INTEGRAL LAUNCH AND REENTRY VEHICLE SYSTEM

NASA-CR-66865 REPORT MDC E0049 CONTRACT NAS 9-9204 NOVEMBER 1969 SERIAL NO. 2/0

VOLUME III PROGRAM PLANS AND COSTS

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MCDONNELL DOUGLAS

FOREWORD

This volume of McDonnell Douglas Astronautics Company Report Number MDC E0049 constitutes a portion of the final report for the "Integral Launch and Reentry Vehicle Systems Study". The study was conducted by the MDAC for the NASA-Langley Research Center under Contract NAS9-9204.

The final report consists of the following:

Executive Summary

Vol. I - Design, Configuration and Subsystems

Vol. II - Performance, Aerodynamics, Mission and Operations

Vol. III - Plans, Costs, Schedules, Technologies

Vol. IV - One and a Half Stage

McDonnell Douglas Astronautics Company gratefully acknowledges the cooperation of the companies which provided technical assistance during this study. They are:

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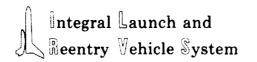
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ABSTRACT

This study emphasized a two stage to orbit reusable spacecraft system for use in transporting cargo and passengers to and from a near earth orbital space station. A single conceptual "point" design was treated in detail and several alternate systems, corresponding to alternate payloads (size and weight), were examined based on parametric excursions from the "point" design. The overall design goal was to configure the carrier and orbiter vehicles to minimize operational and program recurring costs. This goal was achieved through high system reliability, vehicle recoverability, and rapid ground turnaround capability made possible through modular replaceable component design and use of an integrated onboard self test and checkout system. Launch and land landing of both stages at the ETR launch site was a study groundrule as was the nominal 25,000 lb payload delivered to and returned from orbit and packaged in a 15 ft. diameter by 30 ft. long cylindrical canister. The resulting system has a gross lift-off weight of 3.4 million pounds.

The Orbiter is a 107 ft. HL-10 configuration, modified slightly in the base area to accommodate the two boost engines. The launch propellant tanks are integral with the primary body structure to maximize volume available for propellant.

The Carrier is a 195 ft. clipped delta configuration with ten launch engines identical to those of the orbiter. A dual lobed cylindrical launch propellant tank forms the primary body structure. A 15% thick delta wing is incorporated which contains the landing gear, airbreathing engines and propellant.

A broad range of weight, cost and performance sensitivity data were generated for the baseline and alternate system designs. Pertinent development and resource requirements were identified, development and operational schedules were prepared and corresponding recurring and non-recurring cost data were estimated. Program plans were outlined for the design, manufacture and testing of the Orbiter and Carrier vehicles and for the pursuit of critical technologies pacing vehicle development.

Stage and a half and reusable systems employing expendable launch vehicles were considered initially, but, these efforts were subsequently terminated prior to completion. The expendable launch vehicle data are reported separately. The stage and a half effort employed a version of the McDonnell Douglas Model 176 with four drop tanks.

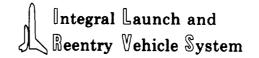
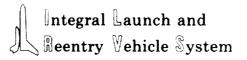
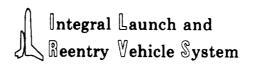


TABLE OF CONTENTS

| PARAGRAPH | TITLE | PAGE |
|-----------|---|------|
| 1.0 | INTRODUCTION | 1-1 |
| 2.0 | PLANS AND SCHEDULES | 2-1 |
| 2.1 | Design and Manufacturing Plan | 2-2 |
| 2.1.1 | Configuration Analysis | 2-2 |
| 2.1.2 | Manufacturing Approach | 2-2 |
| 2.2 | Development Test Plan | 2-15 |
| 2.2.1 | Phase B | 2-19 |
| 2.2.2 | Phase C | 2-19 |
| 2.2.3 | Phase D | 2-19 |
| 2.3 | Facilities Plan | 2-41 |
| 2.3.1 | Manufacturing and Assembly | 2-41 |
| 2.3.2 | Ground Test | 2-45 |
| 2.3.3 | Flight Test | 2-47 |
| 2.3.4 | Operations | 2-47 |
| 2.4 | Launch Operations Plan | 2-49 |
| 2.4.1 | Philosophy | 2-49 |
| 2.4.2 | Analysis | 2-49 |
| 2.4.3 | Erection Techniques | 2-52 |
| 2.4.4 | Launch Operations | 2-54 |
| 2.4.5 | Facilities Analysis | 2-64 |
| 2.4.6 | Ground Support Equipment (GSE) Requirements | 2-65 |
| 2.5 | Maintenance Plan | 2-69 |
| 2.5.1 | Scope | 2-69 |
| 2.5.2 | Maintenance Philosophy | 2-69 |



| PARAGRAPH | TITLE | PAGE |
|-----------|---|-----------------------|
| 2.5.3 | Facilities Requirements | 2-71 |
| 2.5.4 | Types of Maintenance | 2-72 |
| 2.5.5 | Maintenance Planning | 2-72 |
| 2.5.6 | Maintenance Management Procedures | 2-72 |
| 2.6.1 | Vehicle Recovery Plan | 2-77 2 - 77 |
| 2.6.2 | Philosophy | 2-77 |
| 2.6.3 | Normal Recovery Requirements | 2-77 |
| 2.6.4 | Abort Recovery Requirements | 2-78 |
| 2.6.5 | Alternate Launch and Abort Site | 2-79 |
| 2.7 | Program Schedules | 2-81 |
| 3.0 | PROGRAMMATIC ANALYSIS | 3-1 |
| 3.1 | Cost Methodology | 3-1 |
| 3.1.1 | Background | 3-1 |
| 3.1.2 | Cost Estimating Models | 3-2 |
| 3.2 | Programmatic Ground Rules | 3-4 |
| 3.3 | Total Program Cost | 3-6 |
| 3.3.1 | Development Phase | 3-8 |
| 3.3.2 | Investment Phase | 3-12 |
| 3.3.3 | Operation Costs | 3-19 |
| 3.3.4 | Cost Summary and Funding Requirements | .3-24 |
| 3.4 | Cost Effectiveness Analysis | 3-24 |
| 3.4.1 | Payload Cost to Orbit | 3-24 |
| 3.4.2 | Program Recurring Costs/Design Life | 3-32 |
| 3.4.3 | Program Recurring Cost/Recertification Time | 3-35 |
| 3.4.4 | Program Recurring Cost/Reliability | 3-38 |



| PARAGRAPH | TITLE | GE |
|-----------|--|----|
| 3.4.5 | Programmatic Conclusions | 4 |
| 4.0 | SUPPORTING RESEARCH AND TECHNOLOGY PLAN | 1 |
| 4.1 | Technology Analysis Methodology | 1 |
| 4.2 | Approach | 3 |
| 4.3 | Definition of Terms | 3 |
| 4.4 | Technology Requirements | б |
| 4.5 | Plans and Schedules | 6 |
| 4.5.1 | Essential Supporting Research and Technology 4-9 | 9 |
| 4.5.2 | Significant Supporting Research and Technologies 4-2 | 21 |
| 4.6 | Cost Summary | 36 |

LIST OF EFFECTIVE PAGES

Title Page

i through ix

1-1

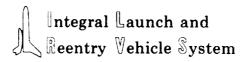
2-1 through 2-85

3-1 through 3-41

A-1 through A-8

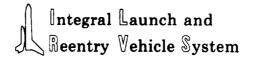
B-1 through B-18

4-1 through 4-37



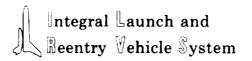
LIST OF ILLUSTRATION

| Figure No. | Title | Page No |
|------------|---|---------|
| 2-1 | Sequential Flow Chart - Orbiter | 2-3 |
| 2-2 | Sequential Flow Chart - Carrier | 2-4 |
| 2-3 | Pictorial Flow Chart - Carrier | 2-6 |
| 2-4 | Pictorial Flow Chart - Carrier | 2-7 |
| 2-5 | Pictorial Flow Chart - Carrier | 2-8 |
| 2-6 | Pictorial Flow Chart - Carrier | 2-9 |
| 2-7 | Pictorial Flow Chart - Orbiter | 2-10 |
| 2-8 | Pictorial Flow Chart - Orbiter | 2-11 |
| 2-9 | Pictorial Flow Chart - Orbiter | 2-12 |
| 2-10 | Pictorial Flow Chart - Orbiter | 2-13 |
| 2-11 | Summary - Baseline Development Schedule For LRC Space Shuttle (10C July 1976) | 2-16 |
| 2-12 | Summary - Stretched Development Schedule for LRC Space Shuttle | 2-17 |
| 2-13 | Summary - Phase D Baseline Ground Test Schedule for LRS Space Shuttle | 2-20 |
| 2-14 | Phase D Baseline Ground Test Schedule for LRC Space Shuttle | 2-21 |
| 2-15 | Summary - Phase D Baseline Ground Test Schedule for LRC Space Shuttle | 2-22 |
| 2-16 | Major Ground Test Hardware Descriptions | 2-23 |
| 2-17 | Summary - Wind Tunnel Tests for LRC Space Shuttle | 2-24 |
| 2-18 | Typical Areas of Structural Development (Carrier) | 2-27 |
| 2-19 | Typical Areas of Structural Development (Orbiter) | 2-28 |
| 2-20 | Summary - Flight Test Schedule for Baseline Development Program | 2-36 |
| 2-21 | Flight Test Schedule for Stretched LRS Space Shuttle Development (10C in Late 1977) | 2-37 |



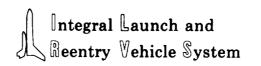
LIST OF ILLUSTRATIONS (Continued)

| Figure No. | Title I | Page No |
|------------|---|---------|
| 2-22 | Flight Test Phases | 2-38 |
| 2-23 | Facility Requirements Summary | 2-42 |
| 2-24 | Schedule - Estimated Facility Availability Requirements | 2-43 |
| 2-25 | Final Assembly Facility Study | 2-44 |
| 2-26 | Summary - Estimated Wind Tunnel Modification Requirements | 2-46 |
| 2-27 | On-Pad Buildup Technique | 2-51 |
| 2-28 | VAB Utilization - Plan View - Vehicle Horizontal | 2-54 |
| 2-29 | VAB Utilization - Side View | 2-55 |
| 2-30 | Vehicle Assembly Building - High Bay Floor Area | 2-56 |
| 2-31 | VAB High Bay Cell - Floor Level | 2-57 |
| 2-32 | VAB Utilization High Bay - Side View | 2-58 |
| 2-33 | Pad Erection Techniques | 2-59 |
| 2-34 | Pad Erection Techniques | 2-60 |
| 2-35 | Minimum Turnaround Summary | 2-70 |
| 2-36 | Maintenance Area | 2-74 |
| 2-37 | Carrier Landing Sites (No Cruise Required) | 2-80 |
| 2-38 | ILRVS Program Schedule | 2-82 |
| 2-39 | Program Milestone Schedule | 2-84 |
| 3-1 | Total Program Cost Element Structure | 3-7 |
| 3-2 | Program Scheduling and Funding | 3-26 |
| 3-3 | Program Scheduling and Funding (Stretched Program) | 3-27 |
| 3-4 | Effects of Payload Capability and Annual Transport Demand | 3-30 |
| 3-5 | Effects of Payload Capability and Annual Transport Demand - 10 Year Program | 3-31 |



LIST OF ILLUSTRATIONS (Continued)

| Figure No. | Title | Page No. |
|------------|---|----------|
| 3-6 | Cost/Design - Life Interaction (Orbiter) | 3-33 |
| 3-7 | Cost/Design - Life Interaction (Carrier) | 3-34 |
| 3-8 | Cost/Recertification - Time Interaction Orbiter | 3-36 |
| 3-9 | Cost/Recertification - Time Interaction Carrier | 3-37 |
| 3-10 | Cost/Reliability - Interaction Carrier | 3-39 |
| 3-11 | Cost/Reliability - Interaction Orbiter | 3-48 |
| 4-1 | Technology Analysis Methodology | 4-2 |
| 4-2 | Technology Tree | 4-7 |
| 4-3 | Technology Flow | 4-8 |
| 4-4 | Configuration Evaluation | 4-10 |
| 4-5 | Boundary Layer Transition and Turbulent Heating | 4-12 |
| 4-6 | Thermo-Structures Analysis | 4-14 |
| 4-7 | TD NiC Material Development | 4-15 |
| 4-8 | Hardened Compacted Fibers | 4-17 |
| 4-9 | High P _C Boost Engine | 4-18 |
| 4-10 | Self-Test For On-Board Checkout | 4-19 |
| 4-11 | Integrated Avionics System Demonstration | 4-22 |
| 4-12 | Data Bus | 4-23 |
| 4-13 | Electronic Controls and Displays | 4-25 |
| 4-14 | Non-Cooperative Rendezvous | 4-26 |
| 4-15 | $^{0}2^{/\mathrm{H}}$ Attitude Propulsion | 4-27 |
| 4-16 | Entry Energy Management | 4-29 |
| 4-17 | Automatic Landing | 4-30 |
| 4-18 | Cruise Engine Vacuum Storage | 4-31 |

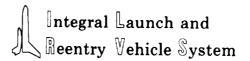


LIST OF ILLUSTRATIONS (Continued)

| Figure No. | Title Page No. | ٠. |
|--------------|--|-------------|
| 4-19 | Integral Tank Design 4-32 | |
| 4-20 | Cryogenic Insulations 4-33 | |
| 4-21 | Coated Refractory Metals 4-35 | |
| 4-22 | Technology Cost Summary 4-37 | |
| | | |
| | LIST OF TABLES | |
| Table No. | Title | Page No. |
| 2-1 | Maintenance Control | 2-73 |
| 3-1 | Programmatic Considerations | 3-5 |
| 3-2 | Total Development Phase | 3-9 |
| 3-3 | Development Cost Summary - Millions of | 3-13 |
| 3-4 | Development Cost Summary - Millions of | 3-14 |
| 3-5 | Investment Phase | 3-16 |
| 3-6 | Investment Cost Summary-Millions of | 3-17 |
| 3-7 | Operation Cost | 3-20 |
| 3-8 | Operation Cost | 3-21 |
| 3-9 | Operation Cost | 3-22 |
| 3-10 | Contractor Program Cost Summary | 3-25 |
| 3-11 | Transport Cost Evaluation | 3-28 |
| 4-1 | Summary of Technologies | 4-4 |

| | | , |
|---|--|---|
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Volume III



REPORT NO. MDC E0049 NOVEMBER 1969

1.0 INTRODUCTION

Program development plans and schedules, and the development (nonrecurring) and operational (recurring) costs were developed on the basis of attaining initial operational capability in mid-1976. Supporting research and technology requirements identified during the course of this conceptual study are scheduled to be initiated in early-1970 in order to prove or disprove feasibility by the beginning of program Phase C and demonstrate development capability prior to final design in Phase D.

Program plans are included for design and manufacturing, development test, facilities, launch operations, maintenance and vehicle recovery. The flight demonstration tests will be conducted with production configuration vehicles and upon completion of the test programs, the vehicles will be refurbished to remove flight instrumentation and restore them to operational configuration. Facility requirements show a minimum requirement for new testing facilities and minimum modifications to existing launch facilities. This is based on the assumption that maximum use will be made of existing facilities and that total MDC, Government and vendor testing capabilities will be at the disposal of the program. An airline type operational philosophy coupled with the primary objective of reducing operational costs led to maintenance and launch operations plans with a six day turnaround time of which only 24 hours is spent on the pad. The programmatic analysis, based on cost methodology developed from several years of advanced design studies, confirms potential order of magnitude reduction in recurring cost for lofted discretionary payload and total lofted payload.

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2.0 PLANS AND SCHEDULES

Development and operational plans and schedules are contained in this section. Development plans include design and manufacturing, development test and facilities. Operational plans are the launch operations, maintenance and vehicle recovery.

The design and manufacturing plan contains an assessment of the manufacturing and fabrication sequence and methodology based on available conceptual design information.

The development test plan contains requirements for ground and flight tests. Flight test schedules were developed for a mid-1976 IOC date and a late 1977 IOC.

Facility requirements for ground testing, manufacturing, flight testing and launch operations are covered in the facilities plan. Requirements for new and modified facilities are shown with the preliminary cost estimates.

The launch operations plan outlines procedures for pre-pad and on-pad erection, mating, checking and servicing the vehicles, and the requirements for aerospace ground equipment to accomplish the launch preparation.

Detailed maintenance procedures developed for the ground turnaround study are the basis for the maintenance plan. In the ground turnaround analysis, the requirements and procedures for performing the maintenance and launch operation functions within an estimated 6 days are identified.

Vehicle recovery, which includes the requirements for both normal and emergency landing sites and the master schedules for accomplishing these development and operations functions conclude the section.

- 2.1 <u>Design and Manufacturing Plan</u> The purpose of this plan is to identify the manufacturing and assembly techniques and procedures for the two-stage fully reusable system. These procedures are based on an analysis of preliminary design data.
- 2.1.1 Configuration Analysis During the study program manufacturing specialists have worked with, and given guidance to Engineering in matters relative to manufacturing techniques and approaches for the preferred design concept of a two-stage fully reusable vehicle. Study of the ILRVS baseline design has shown that a combination of aircraft and spacecraft fabrication practices are best suited to these vehicles. Except for the size, and the probable necessity of a greater number of sub-assemblies, the vehicles will be constructed in a sequence similar to that of present day aircraft, including such assemblies as wings, fins, rudders, flaps, fuselage, etc. A specific example of this is development of an approach to construction of the oxygen and hydrogen integral fuel tanks. The proposed method of assembling, insulating and pressure testing as separate tanks is shown in the Sequential Work Flow Charts, Figures 2-1 and 2-2. These tanks will be broken into longitudinal sections (Body Station to Body Station) for ease of construction and handling.

2.1.2 Manufacturing Approach

- a) Introduction The Manufacturing program begins with coordination of the total fabrication and assembly effort by Production Planning. During the early period schedules are prepared, tooling designed and constructed, priorities established, procurement cycles initiated and piece parts fabrication started. The Manufacturing planning which began during this study phase is discussed in the following sections.
- b) Scope The proposed scope of the manufacturing plans is indicated by the following listing of principal elements. A brief description of each of these elements as well as charts and illustrations are included.
- c) Sequential Work Flow Charts These charts establish an orderly progression of assembly activity for the flight vehicles. Figures 2-1 and 2-2 are preliminary representatives of these charts. Organizing the manufacturing flow in this manner assures a comprehensive consideration of the total

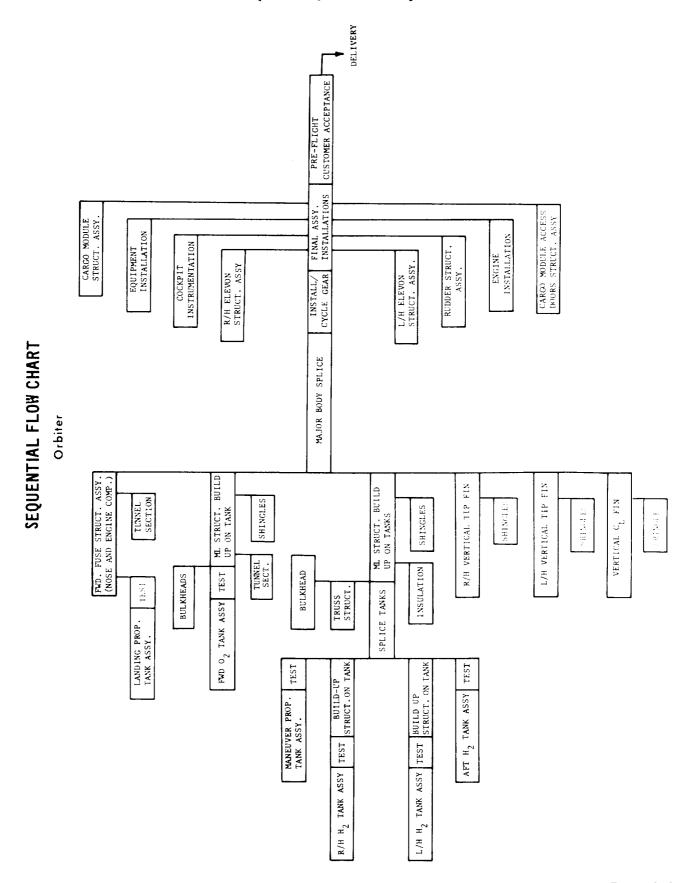


Figure 2-1

Figure 2-2

MDC E0049

- c) (Continued)
 - manufacturing task. It also provides a basis for production schedules, procurement cycles, manloading, tooling requirements and manufacturing cost analysis.
- d) Pictorial Flow Chart These charts are graphic illustrations of the Sequential Work Flow showing the vehicle assembly arrangement. Likewise these charts provide information regarding physical relationships of the various sub-assemblies and assemblies. They are also useful for orientation regarding assembly configurations. Charts for the two vehicles are shown in Figures 2-3 through 2-10.
- e) Fabrication and Assembly Approach The general approach to fabrication and assembly of the two stages shown in Figures 2-3 through 2-10 demonstrates a system of assembly by modules of convenient size for handling, testing and processing. Also these modular sections of the vehicle are shown flowing through a logical assembly sequence to complete the vehicle. Based upon previous aircraft and spacecraft experience, assembly size, complexity and fabrication equipment and facilities were considered in establishing the assembly sequence and flow lines.

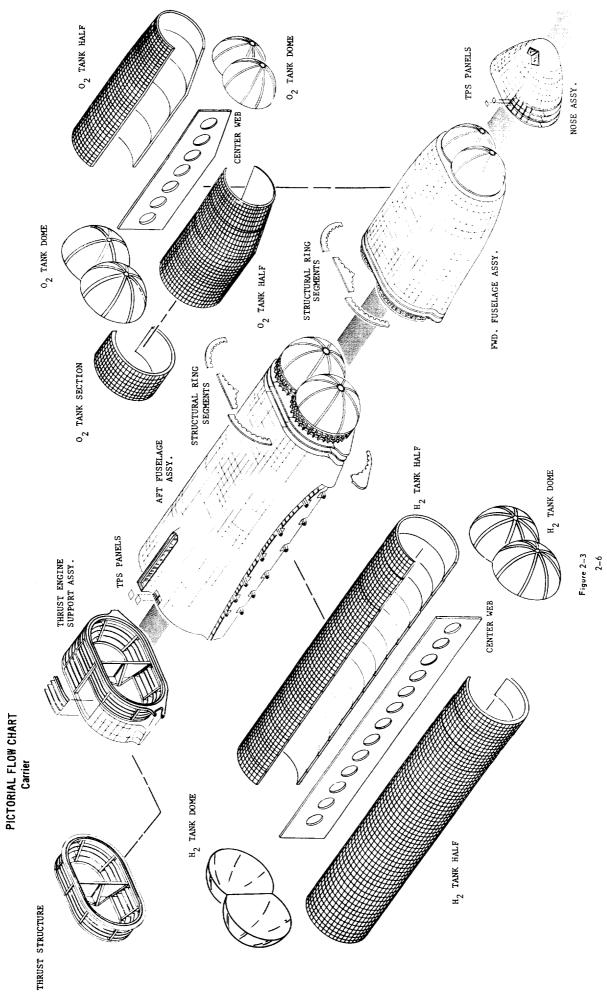
The depth of information available at this time indicates the fabrication and assembly is within the present state-of-the-art. The size of the two vehicles will require handling and processing techniques similar to those used in construction of the S IV B and airline transports.

- f) Schedule The master schedule shown in Figure 2-38, Section 2.7, includes pertinent manufacturing functions which have been coordinated with program objectives. However, detailed manufacturing, tooling, and handling equipment schedules should be developed during Phases B and C. These schedules should be based upon the Sequential Work Flow Chart and the Master Schedule and should effect coordination for the following items:
- o Engineering Drawing Release
- o Tool Design and Construction
- o Piece Part Fabrication Cycles
- o G.F.E. and Vendor Deliveries
- o AGE Fabrication
- o Development of Test and Flight Vehicle Completion Dates
- o Manufacturing Manpower Requirements

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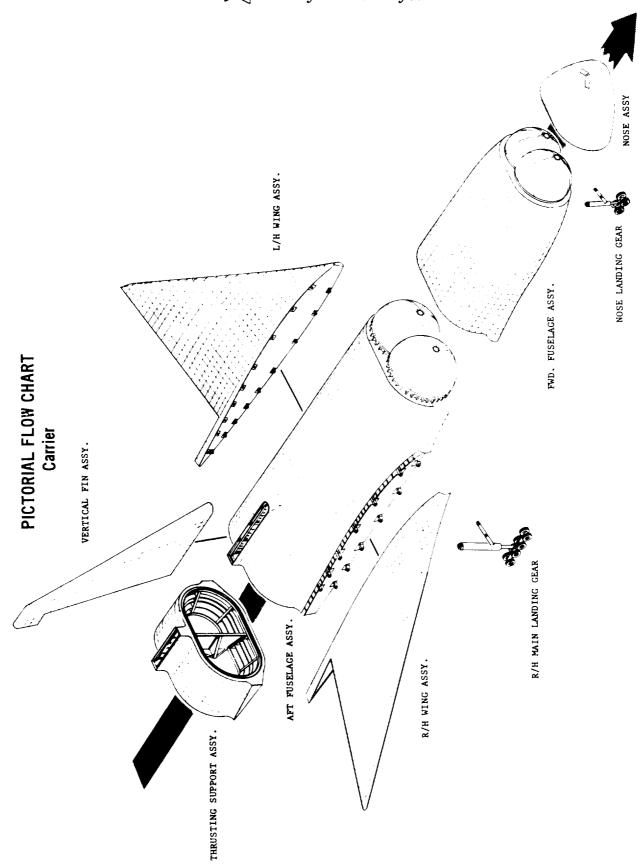


Figure 2-4

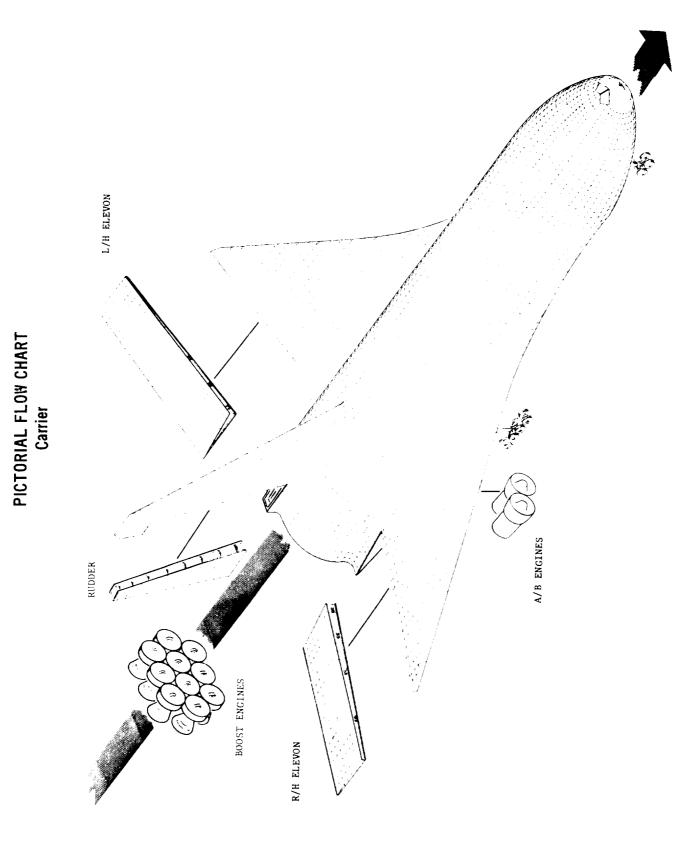


Figure 2-5

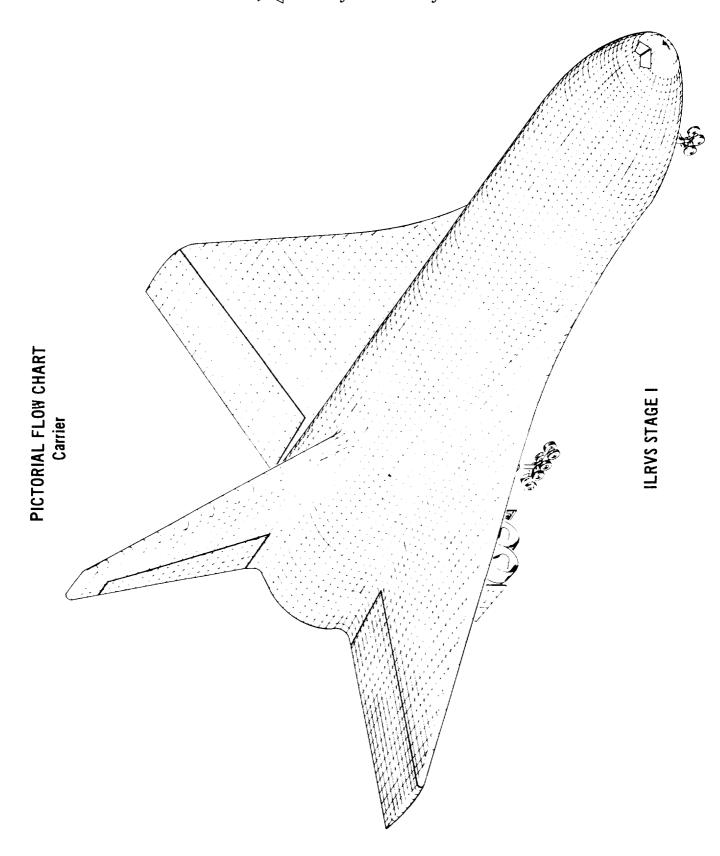


Figure 2-7

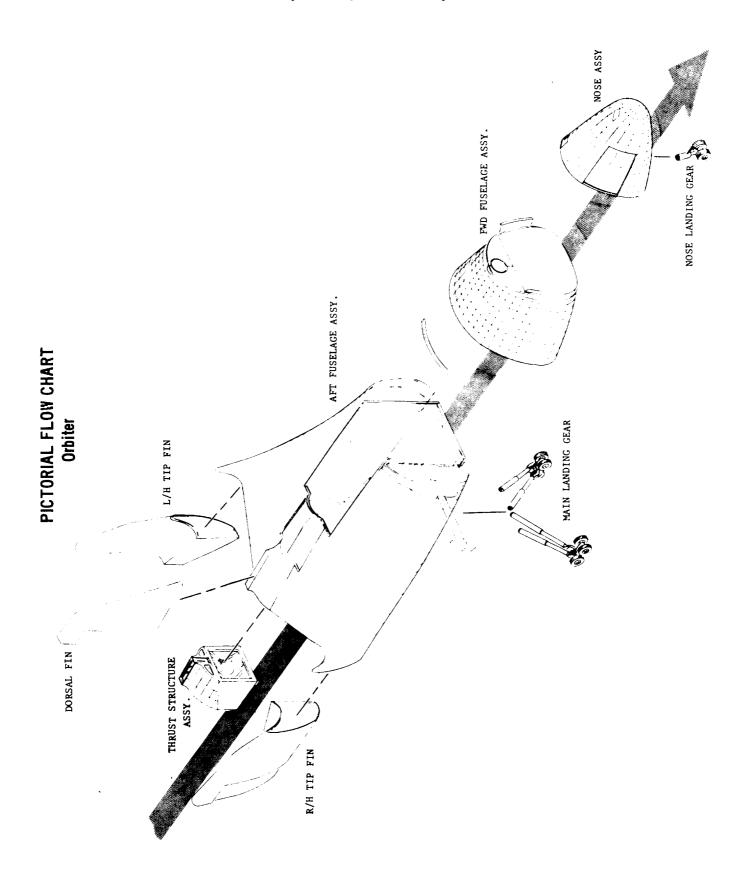


Figure 2-8



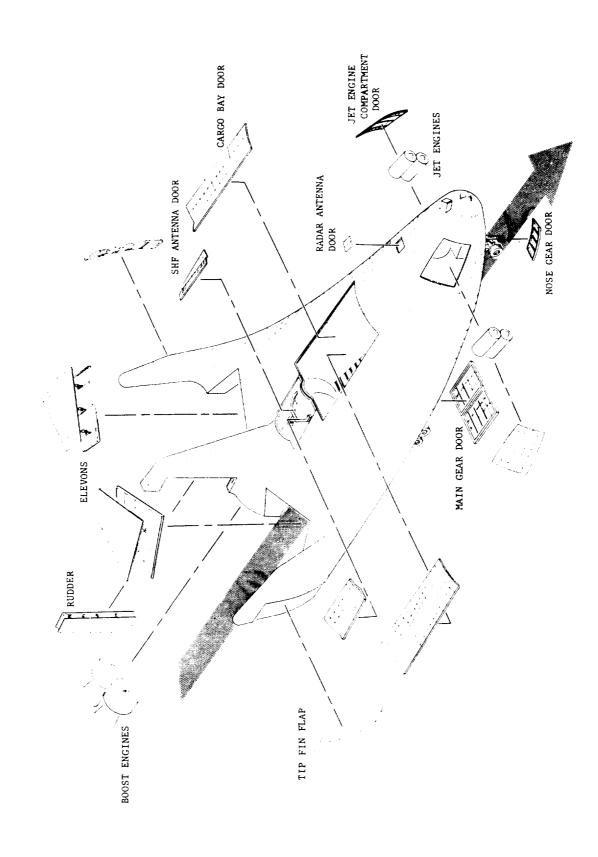
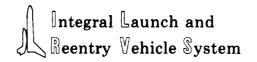
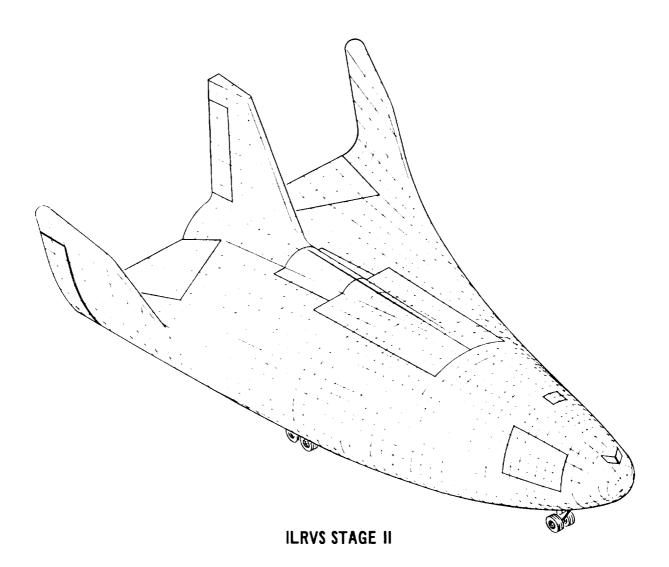
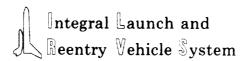


Figure 2-9



PICTORIAL FLOW CHART Orbiter





- f) (Continued)
- o Manufacturing Budget Allocations
- o Availability of Facilities
- g) Tooling Approach The tooling approach adopted has been influenced by the total number of vehicles to be built for this program. Since the anticipated number is small, standard tools and equipment will be used where it is practical to do so. However, it is expected that some special or contract tooling will be required due to the size of the articles being built, tools which otherwise might not have been needed. Likewise, the assembly activity will be planned in such a way as to minimize the need for duplicate tools.

2.2 <u>Development Test Plan</u> - This development test program was defined to provide a basis for establishing development costs, schedules, and identification of time critical development effort where additional definition and study is required. A summary baseline schedule illustrated in Figure 2-11 is based on parallel development of the Orbiter and the Carrier and assumes that technology and research funding is adequate to demonstrate feasibility of all technologies prior to go-ahead on Phase D. The development, manufacturing and flight test efforts of this schedule are considered to be the minimum allowable. The baseline operational program was assumed to have one launch per month and require three Orbiters and two Carriers to meet this schedule. Initial Operational Capability (IOC) occurs in mid-1976 and all five production vehicles are utilized for flight testing.

An alternate schedule, allowing greater time for development, was also considered. That schedule, shown in Figure 2-12 attained IOC in September 1977 with the first stage development started one year after the second stage. This approach would appear to minimize perturbations of the Carrier design, development and manufacturing programs. However, in using this approach there is the possibility that problems encountered in the Orbiter design might be avoided (rather than solved) by constant revision of the Carrier specifications and serious design problems of the Carrier could create detrimental late date modifications to the Orbiter. This could be minimized by a strong integration team and maintaining a "tracking phase C" effort on the Carrier during the 12 month delay period. There is of course the alternative of starting the Carrier at any time program confidence warranted it and thus shorten the IOC period correspondingly.

This section includes definition of the normal development tests and hardware required for the baseline development plan. Section 4.0 of this volume includes definition and discussion of the requirements for supporting research and technologies effort which have been identified as essential or significant to this program.

There are four basic categories of testing in a development program and they are:

O <u>Design Information Tests</u> are performed to obtain design information, where analytical techniques are not adequate, and to evaluate materials, processes, circuitry and mechanisms for design, reliability, safety, and

Volume III

Integral Launcn and Seentry Tehicle Eystem

SUMMARY - BASELINE DEVELOPMENT SCHEDULE FOR LRC SPACE SHUTTLE (10C JULY 1976)

CALENDAR YEARS

REPORT NO. MDC E0049 NOVEMBER 1969

1ST VERTIC ASSUMING PARALLEL DEVELOPMENT OF BOTH STAGES. TESTS CONDUCTED FOR ONE STAGE WHICH ARE APPLICABLE TO BOTH STAGES WOULD NOT B TESTS FOR APPLICATION AND PECULIAR HARDWARE WOULD GENERALLY BE CONDUCTED IN T 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 62 63 64 65 66 67 68 69 70 71 **첫**둘분 ROLLOUTS 90% DWG RELEASE ã 🔀 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 1972 GO-AHEAD CO-AHEAD GO-AHEAD ENGINEERING STUDIES & SPOR PREPARATION CONFIGURATION DEVELOPMENT (WIND TUNNEL TESTS)... MONTHS AFTER GO-AHEAD ENGINEERING STUDIES & COMPONENT SPECIFICATIONS. CONFIGURATION DEVELOPMENT (WIND TUNNEL TESTS). SUPPORTING RESEARCH & TECHNOLOGY PROGRAMS COATED REFRACTORY METALS NEAR --B/L TRANSITION/TURBULENT HEATING-CRYOGENIC INSULATIONS ---------INTEGRATED SYSTEMS DEMONSTRATION. SELF TEST FOR ON-BOARD CHECKOUT. INTEGRAL TANK NON-COOPERATIVE RENDEZVOUS -----ELECTRONIC CONTROLS & DISPLAYS. CONFIGURATION EVALUATION..... THERMO-STRUCTURE..... ENGINEERING DESIGN & ANALYSIS FLIGHT DEMONSTRATION TESTS. TD Ni Cr DESIGN INFORMATION TESTS. PHASE D - ACQUISITION *---PROOF & FUNCTIONAL THERMAL PROTECTION NTEGRATED AVIONICS PHASE B - DEFINITION DEVELOPMENT..... ACTIVITY ACCEPT ANCE DEVEL OPMENT. OUALIFICATION QUALIFICATION PHASE C - DESIGN MANUFACTURING VEHICLE TESTS ROPULSION DATA BUS AGE TESTS DESIGN

0₂/H₂ ACS HIGH Pc ENGINE

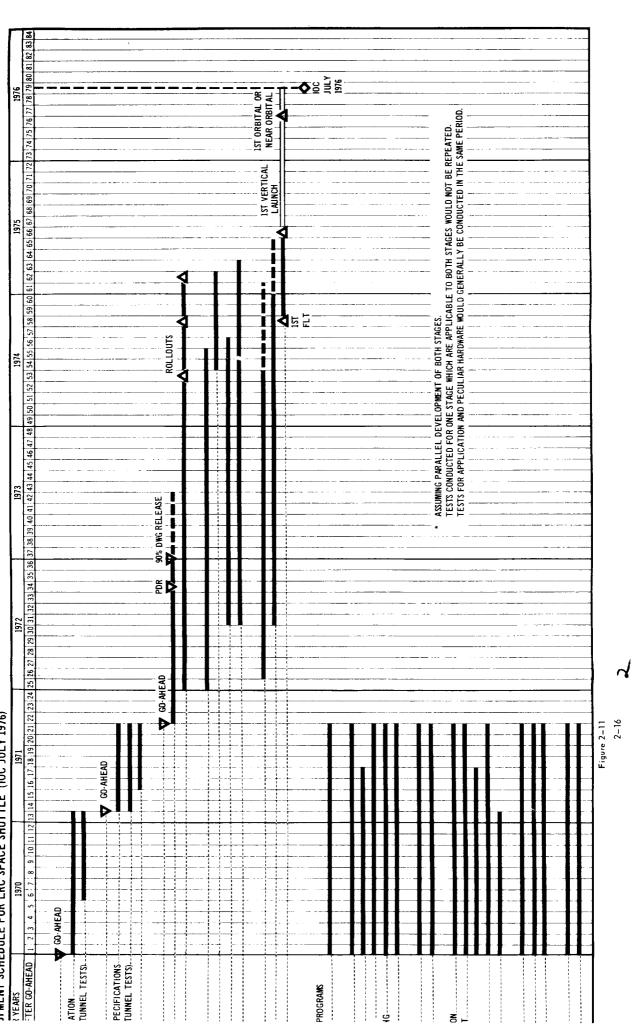
ENTRY ENERGY MANAGEMENT

SUIDANCE & CONTROL

2-16 Figure 2-11

Integral Launch and Seentry Sehicle System

REPORT NO. MDC E0049 NOVEMBER 1969 PMENT SCHEDULE FOR LRC SPACE SHUTTLE (10C JULY 1976)



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Volume III

Integral Launch and Rentry Vehicle System

SUMMARY - STRETCHED DEVELOPMENT SCHEDULE FOR LRC SPACE SHUTTLE

REPORT NO. MDC E0049 NOVEMBER 1969

₩ 1ST ORBITAL OR NEAR ◁ ROLLOUTS 90% DESIGN 90% DESIGN RELEASE GO-AHEAD ORBITER PHASE D-ACQUISITION ENGINEERING DESIGN & ANALYSIS MANUFACTURING GROUND TURING PROOF & FUNCTIONAL TESTS QUALIFICATION TESTS FLIGHT TESTS FLIGHT TESTS CARRIER PHASE D. ACQUISITION ENGINEERIND DESIGN & ANALYSIS. MANUFACTURING GROUND TESTS PROOF & FUNCTIONAL TESTS QUALIFICATION TESTS ACCEPTANCE TESTS FLIGHT TESTS CARRIER PHASE C – DESIGN (TRACKING EFFORT)...... INTEGRATED LAUNCHES..... AGE DESIGN AND ANALYSIS DEVEL OPMENT...... QUALIFICATION.......... ACTIVITY

ORBITAL

2-17 Figure 2-12

refurbishment characteristics. The test articles may be components, breadboards, subsystems, or spacecraft models as necessary to evaluate the condition or function of interest. The tests are normally informal, with test documentation and control as internal company functions.

- o <u>Design Verification Tests</u> are performed to verify that the design functions as intended and has the required characteristics. These include design characteristics such as strength, performance, fit and interface compatibility. These tests include overstress tests to determine margins of performance. In some cases design verification tests can be combined with qualification tests.
- O Qualification Tests are formal tests generally conducted by vendors or McDonnell Douglas on production hardware. They are conducted at or above expected mission levels for all critical environments. These tests assure that the hardware design, manufacturing processes, and quality control meet the specification requirements without prior written concurrence from the customer and McDonnell Douglas.
- o <u>Flight Demonstration Tests</u> are conducted with production configuration vehicles prior to the Operational Phase. These flights verify the total performance of the vehicle and its subsystems. Upon completion of these tests, the vehicles are refurbished to remove flight instrumentation and restored to production configuration. See Figure 2-20 for numbers and types of flight tests.

These test categories, except flight test, are applicable to Aerospace Ground Equipment (AGE) as well as flight equipment.

In practice, the need for each test is determined on an individual basis depending on item complexity, mission criticality, environment and cost. Considerations which influence decisions concerning the timing of any particular test or that the cost of that test is justified are:

- o The complexity of the design and associated interfaces.
- o The confidence which can be placed on the analytical technique used as a basis for the design.
- o The schedule and cost effects of a potential failure later in the program. Past experience has shown that even the most rigorous analyses cannot fully and adequately account for the myriad or interrelated factors which go into the design of complex systems. Similarly, testing alone cannot result in a satisfactory product without adequate analysis.

 Analysis and test serve as a check and balance.

- 2.2.1 Phase B During this phase primary efforts are directed towards preparation of the system specification and a preliminary design definition of the systems required hardware and facilities. These efforts require engineering trade studies and analysis, supported with computer programs and configuration development wind tunnel tests.
- 2.2.2 Phase C The preliminary designs are firmed up and subsystem specifications prepared during this phase. Most of the subsystem configuration trade studies would be completed and intra sub-system trades accomplished. Configuration development wind tunnel testing would be accelerated and approximately 7-8000 more test hours would be required to assure a firm configuration for the Phase D hardware design and development effort. In addition to the wind tunnel configuration development tests, design development tests would be started on some of the subsystems.
- 2.2.3 Phase \underline{D} Initiation of long lead procurement action at go-ahead, final hardware design, fabrication and testing are accomplished in this phase. The feasibility of all of the technologies to be incorporated into the design would be demonstrated before this phase is started.

Engineering designs are approximately 90% complete by the 15th month, manufacturing efforts on some test hardware start as early as the 4th month and the first flight test vehicles roll out in the 32nd month and fly about 5 to 6 months later.

Development and verification testing of new components include performance/ demonstration tests of complete systems, and integration tests of several systems. Functional and/or proof tests of some systems are performed on the first flight articles prior to first flight. Figures 2-13, 2-14 and 2-15 are detailed schedules of the estimated test requirements for both the Orbiter and the Carrier. However, since both have essentially the same test program requirements the following paragraphs which discuss the testing approach and philosophy for each of the categories in Phase D are applicable to both except as noted. Figure 2-16 lists and defines the major test hardware items.

Wind Tunnel Tests - Wind Tunnel tests which are conducted prior to Phase D are directed toward configuration analysis, definition and development. Tests conducted after Phase D go-ahead includes performance verification testing also. Figure 2-17 shows the types of tests which would be conducted in the various flight regimes. A definition of the four basic types of wind tunnel testing on scale models are:

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SUMMARY - PHASE D BASELINE GROUND TEST SCHEDULE FOR LRC SPACE SHUTTLE

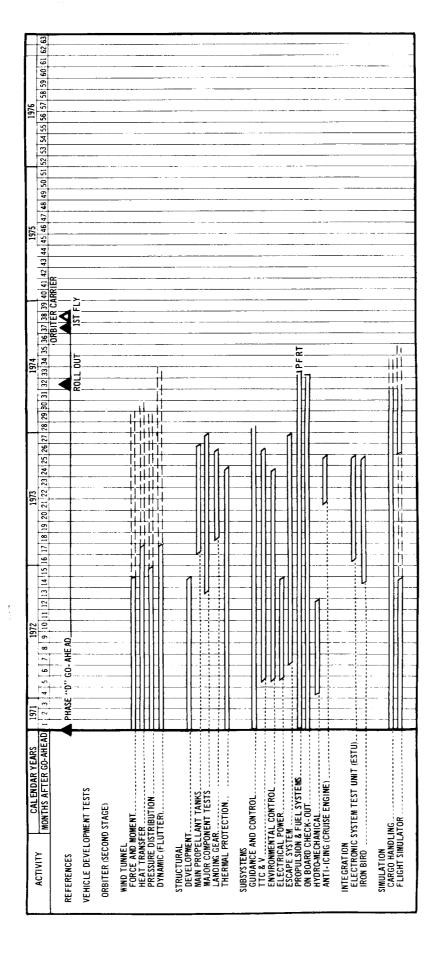


Figure 2-13 2-20

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Integral Launcn and Sentry Vehicle System

REPORT NO.

MDC E0049 NOVEMBER 1969

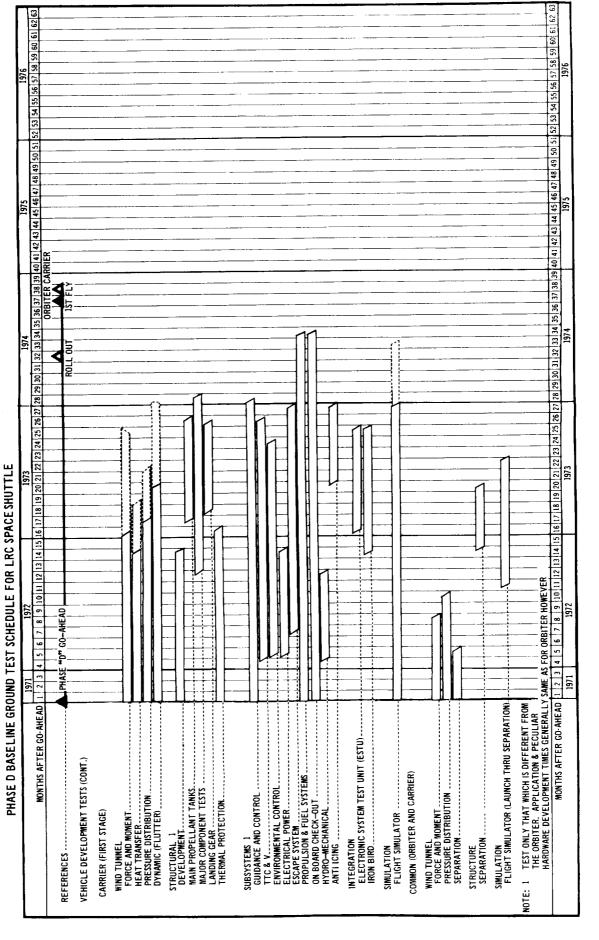
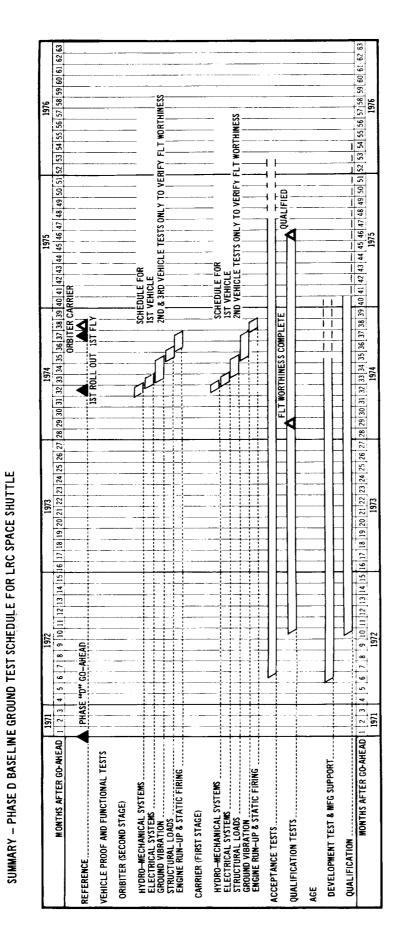


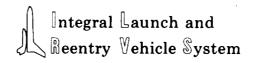
Figure 2–14

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MAJOR GROUND TEST HARDWARE DESCRIPTIONS

| MAJOR STRUCTURAL COMPONENTS | PRODUCTION CONFIGURATION STRUCTURAL COMPONENTS UTILIZED TO DEMONSTRATE STRUCTURAL ADEQUACY. SECTIONS WILL ONLY BE STRUCTURAL AREAS OF GREATEST CONCERN, NOT A COMPLETE AIRFRAME. |
|--|---|
| MAIN PROPELLANT TANKS | FULL SCALE PRODUCTION TANKS OF REDUCED LENGTH, (MINIMUM LENGTH OF 2 DIAMETERS + DOMES) USED TO VERIFY PRESSURE CYCLE LIFE. ONE FULL SCALE TANK FOR ULTIMATE LOADS PLUS PRESSURE TEST. |
| LANDING GEAR | PRODUCTION CONFIGURATION HARDWARE INCLUDING BACKUP STRUCTURE. UTILIZED TO DEMONSTRATE STRUCTURAL ADEQUACY, AND DEVELOP LOAD-STROKE CHARACTERISTICS. |
| ELECTRONIC SYSTEMS TEST Unit (ESTU) | FULL SCALE MOCK-UP OF SELECTED SECTIONS OF THE VEHICLE TO PROVIDE MOUNTING FOR ALL ELECTRICAL/ELECTRONIC EQUIPMENT AND WIRING IN PROPER RELATIONSHIP. MAY INCLUDE DEVELOPMENT CONFIGURATION EQUIPMENT TO EVALUATE ELECTRONIC COMPATIBILITY AND EMI. |
| IRON BIRD | FULL SCALE BOILER PLATE FRAME WORK OF SELECTED VEHICLE AREAS WHICH HAS PROVISIONS TO MOUNT ALL MECHANICAL, ELECTRO-MECHANICAL, HYDRAULIC, AND AUTOMATIC FLIGHT CONTROL SYSTEMS IN THEIR PROPER RELATIONSHIP. USED TO TEST AND EVALUATE THE FLIGHT CONTROL SYSTEMS. |
| FLIGHT TEST VEHICLE | FULL SCALE PRODUCTION UNITS WHICH WILL INITIALLY BE FLOWN, WITHOUT SOME SUBSYSTEMS WHICH ARE NOT REQUIRED IN THE EARLY PART OF THE FLIGHT DEMON. STRATION PROGRAM, AND WITH SOME PRODUCTION SUBSYSTEM COMPONENT WHICH HAVE BEEN FLIGHT WORTHINESS TESTED BUT NOT FULLY QUALIFIED. THESE SUBSYSTEMS AND COMPONENTS WOULD BE ADDED OR REPLACED AS THEY BECAME AVAILABLE OR ACCORDING TO THE FLIGHT PROGRAM'S NEEDS. |

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| | | CONFIGURATIO | CONFIGURATION DEVELOPMENT | | | PERFORMANCE | PERFORMANCE VERIFICATION | |
|---------------------------------|------------|--------------|---------------------------|------------|----------|-------------|--------------------------|------------|
| | SUBSONIC | TRANSONIC | SUPERSONIC | HYPERSONIC | SUBSONIC | TRANSONIC | SUPERSONIC | HYPERSONIC |
| ORBITER | F&M,P | F&M,P, | F&M,P,D | F&M,P,HT | F&M,P,D | F&M,P,D | F&M,P,D, | F&M,P,D,HT |
| CARRIER | F&M,P | F&M,P | F&M,P,D | F&M,P,HT | F&M,P,D | F&M,P,D | F&M,P,D | F&M,P,D,HT |
| COMPATIBILITY (STAGES TOGETHER) | F&M, P | F&M,P | F&M,P,D | F&M,P,HT | F&M.P.D | F&M,P,D | F&M,P,D | F&M,P,D,HT |
| ESTIMATED TOTAL TUNNEL HOURS | NNEL HOURS | (18,000) | (| | | (12,000) | 000) | |

7,500 OCC. HRS (CONFIGURATION DEV) 20,000 OCC. HRS (CONFIG DEV & PERFORMANCE VERIFICATION) PHASE B PHASE C

2,500 OCC. HRS (CONFIGURATION DEV)

ESTIMATED TOTAL TUNNEL HOURS PHASE D

30,000 OCC. HRS (EXCLUDES ESTIMATED 8000+ HRS CURRENTLY SPENT ON HL-10)

F&M - FORCE & MOMENT TESTS
P - PRESSURE TESTS
HT - HEAT TRANSFER TESTS
D - DYNAMIC (FLUTTER) TESTS

- Aerodynamic force and moment data are derived using a balance mounted scale model.
- o Heat transfer data are derived from a scale model which has gages located in the areas of interest and/or has a coating of temperature sensitive point.
- o Pressure distribution data are derived from a scale model which has pressure transducers or orifices located in the areas of interest on the model surface or in engine ducts.
- o Dynamic response data are derived from dynamically similar scale models of the complete configuration or parts thereof such as wings, tails, etc. These models are instrumented with accelerometers and/or strain measuring devices to measure the model forces and response.

It is estimated that the total amount of wind tunnel testing will be 30,000 hours including those hours from Phases B and C but not including the current 8,000 plus hours already expended on the HL-10 configuration development.

Structural Tests - The structures development and verification test program will include a) material tests where needed characteristics data are not available; b) prototype element and component tests to provide data where analysis techniques are not adequate and c) verification test of major structural components to critical ultimate conditions or failure.

The major feature of this program is that no complete static test vehicle is required; verification tests on instrumented major components to be tested to ultimate conditions will provide data to compare with similar data obtained during proof test loadings (to limit load) of the first flight article. This procedure is the same as has been followed in large transport structures. (DC 8, 9 & 10). Upon completion of the structural verification tests the structures will be considered to be qualified.

Major structural components will include wing carry-through structure; wingbody attachment structure, complete horizontal and vertical tail structure; thrust structure and related aft fuselage and main propellant tank structure; landing gear and back-up structure; pressurized cabin and tunnel structure; control mechanisms, stage-to-stage interconnect structure, and TPS panels and support structure. In addition, pressure cycling tests and burst pressure tests will be performed on main propellant tank structure.

Ultimate strength tests will also be conducted on all major fittings and mechanisms as well as functional performance tests as applicable. Representative items in this category are; windows, hatches, doors & door operating mechanisms, cargo deployment mechanisms, air breathing engine mounts, and major mass item support structures.

Proof loading of the nose and main gear and its support structure is accomplished on one of the flight test vehicles. The landing gear (including wheels, tires and brakes) is qualified by component testing. The nose and main gears are tested with the gear installed in separate test fixtures which incorporate representative local supporting fittings. The loading will be continued to the design ultimate load for critical conditions. The landing gears from the structural flight demonstration vehicles are instrumented and installed in these test setups for calibration prior to use for measuring loads during the flight test program.

Testing is required to develop a reusable heat protection system which has the required capability to withstand the re-entry heating, and flight loads for 100 flights. Material testing would start prior to and continue into Phase D (Reference supporting research and technology in Section 4.0). Tests include material properties at elevated temperatures. Elements, components, and panels would be tested under repeated loads and temperature cycles. Data from these tests would be useful in the establishment of inspection and refurbishment procedures.

Figures 2-18 and 2-19 illustrate typical structural development testing areas.

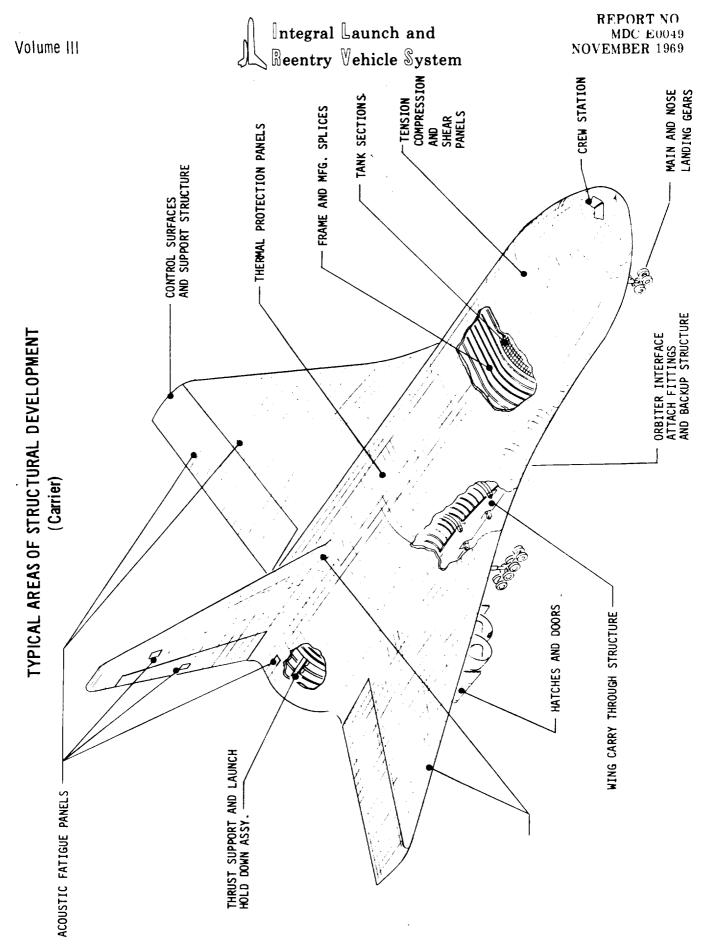


Figure 2-18

In addition to the above static load testing, dynamic structural tests are conducted on the same areas. These tests include modal vibration surveys, environmental vibration qualification tests of equipment and component items, drop tests and model flutter and vibration tests to verify structural integrity and reliability. Ground vibration tests would be conducted on the first flight test vehicles to obtain symmetric and non-symmetric vibration modes and frequencies pertaining to flutter.

Subsystem Tests - The subsystem development and verification test program is based on an established background of procuring and integrating components and subsystems into high performance systems and space vehicles such as the F4, ASSET, BGRV, Mercury and Gemini and the S-IVB booster. The program consists of systematic in-house and vendor testing of components, subassemblies, assemblies and complete subsystems. Testing for each subsystem involves development of components and performance/demonstration tests. (Reference Section 4.0 for additional data applicable to pacing subsystems and components). Component and subsystem development tests which are applicable to both stages would not be duplicated, only those tests required due to different installation or application of the subsystem or its components would be conducted.

The following are major areas of subsystems testing:

Guidance and Control - Testing would start with buildup and test of breadboard circuits of subsystem components, and bench testing to confirm interfaces, optimize subsystem matching and tolerance parameters and bench tests to confirm functional performance. As the subsystem design evolves, three axis motion table tests would be conducted to evaluate system response and interactions, also the guidance and control systems would be installed in the ESTU and flight simulator to assure compatibility with other systems and to develop gains and signal shaping network characteristics to optimize the performance of the various portions of the subsystem. The automatic landing and non-cooperative rendezvous portion of the guidance and control systems will be mostly new state-of-the-art equipment and require complete qualification testing.

Telecommunications - Much of the telecommunications system will be current state-of-the-art and, therefore, component and system development tests would be minimized. Testing includes some of the usual breadboard and bench testing to evaluate component interface problems, and integration and compatibility tests in the ESTU. Antenna pattern tests will be conducted to determine their locations.

REPORT NO. MDC E0049 NOVEMBER 1969

It is expected that one of the major telecommunications problems will be the development of high tempeature and high transmissability antenna windows. To solve this will require a coordinated material development program.

Environmental Control - The ECS system is composed of four main
assemblies:

- o Atmosphere gas supply and management
- o Gas Management and processing assembly
- o Heat transport circuit assembly, and
- o The water supply and management assembly

Components of these assemblies would be tested separately, then as integrated systems for qualification. Examples of typical types of tests are presented in the following paragraphs.

Water boilers will be tested over a range of coolant pressures, orbital environments, and cabin heat transfer rates to determine heat interchange and plumbing pressure drop and also to determine environmental effects on pressurized and unpressurized systems.

Water supply subsystem component tests will consist of development of prepressurized water tanks, water dispensing devices, and humidity condensate collector.

Electrical Power - Electrical power is derived from $\rm H_2/\rm O_2$ fuel cells and/or AgO-Zn batteries. Testing includes environmental tests and functional tests under load at nominal and off-nominal conditions to evaluate subsystem performance and characteristics.

Escape System - A crew escape system would be installed only during the development flight test portion of the program. A previously fully qualified rocket ejection seat would be used. Therefore, development and qualification tests will be conducted only to prove its application. Structural differences would be tested in the structural test program. Subsystem ejection tests are conducted to evaluate timing sequence, separation trajectory, and recovery system deployment. These tests are conducted at conditions which are representative of those which would be encountered within its usage envelope.

<u>Propulsion and Fuel Systems</u> - Currently it is estimated that the most pacing item to be developed for this program is the large high Pc boost engine. The

development of this item is discussed in Section 4.0. Generally, the development test cycle for re-entry control system, and orbit attitude propulsion systems will be the same. The individual system components will be development tested, that is motors fired to evaluate thrust characteristics for various conditions, disassembled to evaluate component conditions, and integrated with the developed fuel feed system to evaluate performance. Tests would be conducted to verify pressure and supply adequacy, liquid flow system and tankage designed. During the boost engine static firings dynamic environments are measured to verify the levels for use in the structural dynamic test programs. Total subsystem integration and functional demonstration of all but the boost system are verified by engine firings in boiler plate spacecraft structure with production design fuel systems after being subjected to flight environments. Verification of the total boost engine installation and fuel system are demonstrated by static firing in the first flight test vehicle. Servicing tests will determine procedures for filling, dump and purge.

On-board Checkout - On-board checkout development would be started prior to acquisition phase go-ahead (reference technology writeup in Section 4.0). Testing includes bench and breadboard tests to develop system components, confirm interface characteristics, optimize component and subassembly matching and tolerance parameters, and to de-bug existing problems. Subsystem compatibility is verified by installation of the on-board checkout system into the ESTU. Operational performance would be verified during flight test.

Hydro-Mechanical - An extensive test program would be conducted on the hydro-mechanical systems. This includes landing gears, control system, and airbreathing engine extension mechanism. The total hydraulic system is functionally ground tested and proof pressure tested on the flight test vehicles.

Development tests include functional and endurance cycling tests with appropriate loads and pressures on spacecraft configuration rigid tubing, coiled tubes and other critical plumbing installations. Also, functional and cyclic tests are conducted on components and associated plumbing such as:

- o Landing gear and airbreathing engine actuating cylinders and mechanisms.
- o Gear door actuators, control valves and latching cylinders.
- o Primary flight control subsystem and high lift device actuators, control valves and mechanisms.

The hydraulic system associated with the flight controls is tested with the guidance and control system on the Iron Bird.

Anti-Icing - Development testing is conducted to design and verify subsystem components and system functional capabilities of the anti-icing system for the airbreathing engine. Tests will establish proper flow and orificing. This subsystem will be further evaluated and demonstrated during the flight test program.

Integration - In addition to the component and subsystem development and integration tests of the various electrical/electronic and hydromechanical subsystems, they will be installed in the flight control system integration test stands ("Iron Bird") and/or the Electronics Systems Tests Units (ESTU) for integration and compatibility tests between the subsystems. The following paragraphs describe the testing to be accomplished with these setups.

Electronic System Test Units (ESTU) - The ESTU is a simple mockup of appropriate materials (wood, aluminum, pilot rum structural elements) which provides for mounting the electrical/electronic equipment and subsystems in the proper physical relationship. Tests of the integrated avionics system, described in Section 4.3, Volume I, Book 1 of this report, would be conducted in the ESTU. Due to the size of the vehicles complete full scale mockups will not be used. Only selected full scale sections, where the avionics and other equipment are concentrated would be fabricated.

With this setup, the interface compatibility can be developed and verified. Individual subsystem and system performance can be evaluated for nominal and off-nominal operating conditions. Electro-magnetic interference (EMI) measurements can be performed to assess EMI control effectiveness.

These tests are conducted as early as possible in the development to allow corrective action (if necessary) with the minimum of schedule impact.

<u>Iron Bird</u> - This test stand consists of full size and geometrically similar sections of the spacecraft airframe. So far as possible, actual production components are located and installed in the proper relationships. This setup is a tool which permits early resolution of:

- o Prototype hardware performance and function
- o Determination of system dynamic characteristics through tie-in of computer simulation of complex mechanisms and characteristics.
- o Total system integration

o Pilot evaluation through tie-in of the motion base flight simulators cockpit. Actual tests include component functional performance for nominal and off-nominal conditions, subsystem interface compatibility and system gains, signal levels and hysterisis.

The primary flight control systems included in this setup and testing will be the automatic landing, attitude control system, rendezvous (for the Orbiter only), and the primary and secondary flight control systems and their respective trim systems.

<u>Simulation</u> - Early in the Space Shuttle program, two types of simulators are required to develop cargo handling and flight handling requirements and techniques. These two types of simulators are:

- o Cargo handling simulator (for the Orbiter) and
- o Flight Simulator (for both stages).

Use of the cargo handling simulator during Phase D is directed towards design and requirements refinement and crew training.

The flight simulators are used as design tools during the initial development of the flight control systems. They are integrated into the "Iron Bird" test setups where pilot evaluations will be conducted on cockpit procedures, displays and general arrangement. In the latter phases of Phase D, the setups are used as flight crew training devices.

<u>Vehicle Proof and Functional Tests</u> - Tests to be conducted on the first flight test units before they are flown are:

Hydro Mechanical - The control system would be proof tested and operationally demonstrated. The hydraulic system is functionally ground tested and all lines pressurized to 150% of the operating pressure and the system inspected for leakage, failure or deformation.

<u>Electrical System</u> - The electrical power system would be tested to ensure performance of the production system. Tests include controlled fault simulations and system compatibility tests on various configurations.

Structural Tests - Design limit loads for critical load conditions are statically applied and main propellant tanks are pressure tested.

<u>Ground Vibration</u> - Ground vibration tests are conducted to verify mode shapes and amplitudes. These tests also provide data to support flutter

analysis and verify structural integrity.

Engine Rum-up and Static Firings - The airbreathing engines are deployed and rum-up to verify performance, fuel system function and flow, and controllability. Prior to the vertical launches, and boost engines are static fired in the flight vehicle to verify fuel system and motor performance. This test also serves to verify dynamic response analysis and testing.

The other flight articles receive essentially the same tests but the scope of the tests would be reduced to prove flight worthiness only (unless of course problems are encountered on the first articles which cause significant modification to the second articles).

Qualification Tests - Formal tests are conducted by McDonnell Douglas or subcontractors and vendors on production hardware. These tests are conducted at environments established by the NASA and McDonnell Douglas to assure the hardware design manufacturing processes and quality control meet the specification requirements.

Acceptance Tests - Acceptance tests are categorized as all testing performed on flight equipment to ensure its capability to perform its assigned mission. These tests are performed by the vendor prior to delivery, and by a Ground Support Operations (GSO) group at McDonnell Douglas and the maintenance site. Spacecraft systems tests are acceptance tests that are performed at various levels of manufacture. Some pre-installation testing is performed to verify that the unit has not been damaged during shipment, and to obtain reference baseline reusability data. Acceptance testing at the maintenance and launch sites will be enhanced by using the on-board checkout system.

Aerospace Ground Equipment (AGE) - AGE tests are performed, monitored or supported as applicable in the categories of development, qualification and acceptance. In general, AGE items are considered as qualified for operational support after they have successfully completed support of acceptance tests, spacecraft proof and functional tests, development flight tests and the FACI.

Development Flight Tests - The objectives of the Space Shuttle Flight Test Program are to evaluate, develop, and demonstrate the Space Shuttle System (including all subsystems) throughout its design operating envelope in an efficient, low cost, and timely manner, consistent with crew and vehicle safety.

Figures 2-20 and 2-21 show the baseline flight test schedule which achieves IOC in mid-1976 and the stretched schedule which achieves IOC in September 1977 as discussed in Section 2.2, Paragraph 2.

Inasmuch as the Space Shuttle System is being designed for operations using airline operation concepts, it is planned to use an approach to flight testing that is similar to the airplane approach. In airplane flight testing, all flights are manned and exploration of the flight operating envelope is done in "build-up" fashion. That is to say, those portions of the flight envelope from which there is a high degree of confidence of recovering the vehicle without damage are entered first, and sorties into other areas are entered from this regime - always attempting to retain options allowing return to this regime in case problems are encountered. The two-stage system lends itself readily to this approach in the low speed, low altitude flight region, but as the envelope approaches orbital conditions the test approach closely resembles the past spacecraft programs with near orbital or orbital launches.

Test Approach - For each of the schedules, testing is divided into phases as shown in Figure 2-22. A definition of each of these phases, test phase objectives, and considerations for further studies in Phase "B" are as follows:

o Phase I

<u>Definition</u> - This phase is the low altitude low speed flight regime. Tests are conducted on the landing, cruise and ferry configurations. Flight investigations in this area would be entered using a horizontal takeoff and would be followed by a horizontal (normal) landing.

<u>Test Objective</u> - Objectives include evaluation, development, and demonstration of flying qualities, performance, structural integrity, propulsion system, and other subsystems together with crew/vehicle interface in the subsonic flight region.

<u>Considerations</u> - This area of flight investigation appears straight forward from an airplane test standpoint and no unusual problems are apparent. For reasons of flight safety, it will be desirable to use thrust augmentation on the Orbiter.

o <u>Phase II</u>

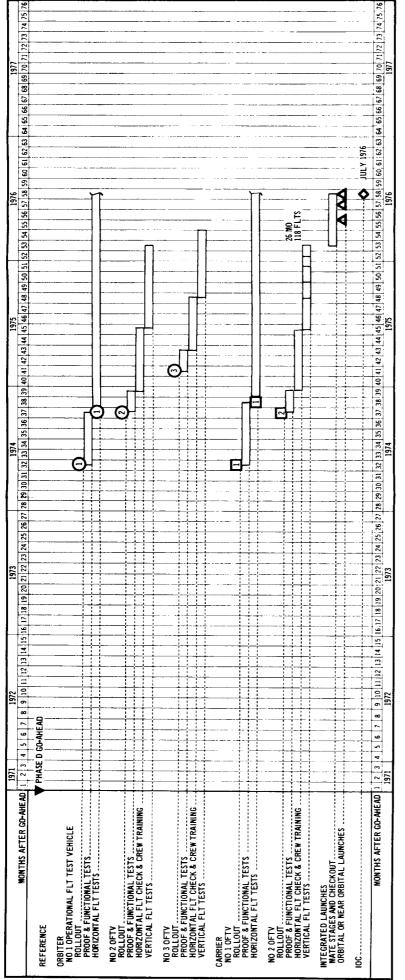
<u>Definition</u> - This phase will investigate the envelope in the transonic and hypersonic regime. Launch may be vertical and normal horizontal landings will be made.

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Integral Launcn and Reentry Vehicle System

REPORT NO. MDC E0049 NOVEMBER 1969

SUMMARY - FLIGHT TEST SCHEDULE FOR BASELINE DEVELOPMENT PROGRAM



140 HORIZONTAL FLIGHTS (SUBSONIC) IN 32 MONTHS 6 VERTICAL FLIGHTS (TRANSONIC-HYPERSONIC) IN 14 1/2 MONTHS ORBITER

118 HORIZONTAL FLIGHTS (SUBSONIC) IN 26 MONTHS 5 VERTICAL FLIGHTS (TRANSONIC-HYPERSONIC) IN 14 MONTHS CARRIER

3 ORBITAL OR NEAR ORBITAL FLIGHTS IN 5 MONTHS INTEGRATED

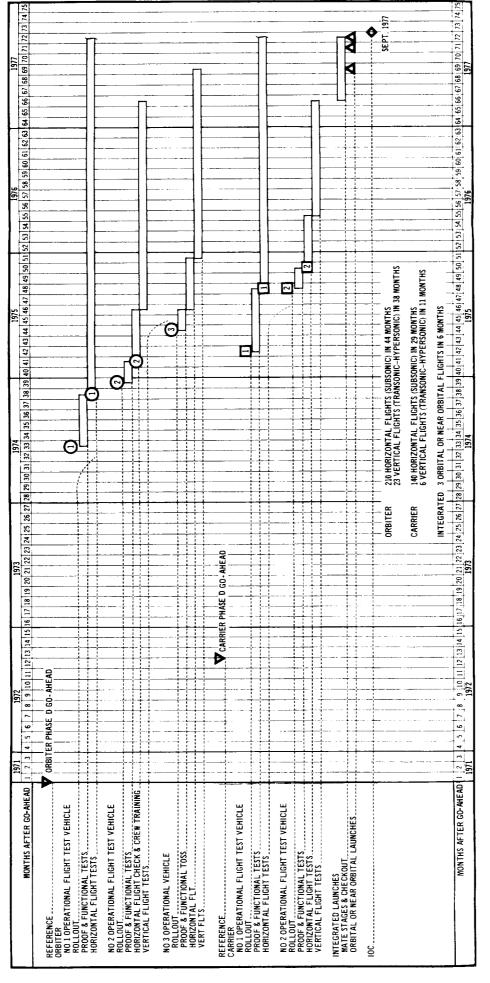
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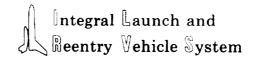
MDC E0049 NOVEMBER 1969

FLIGHT TEST SCHEDULE FOR STRETCHED LRC SPACE SHUTTLE DEVELOPMENT PROGRAM (10C IN LATE 1977)

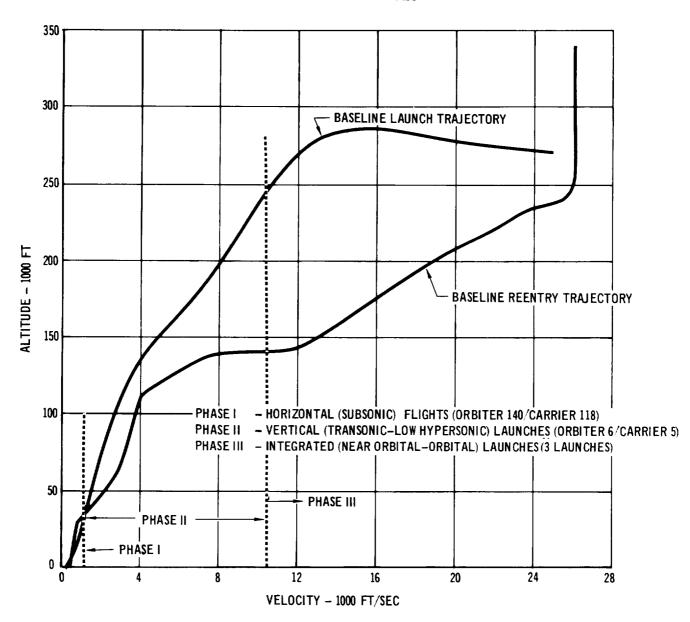


2-37 Figure 2-21

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FLIGHT TEST PHASES



REPORT NO. MDC E0049 NOVEMBER 1969

Test Objectives - Objectives include:

- a. Evaluation and development of reaction control system in flight.
- b. Investigation of flying qualities in transonic region.
- c. Development of transition technique from glide to subsonic flight.
- d. To obtain quantitative information relative to the thermal protection system in a progressive or buildup manner, and data for maintainability.

o Phase III

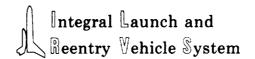
<u>Defintion</u> - The progressive buildup of previous testing naturally and confidently brings the program to this phase which covers the range of flight conditions attainable only by integrated launches into orbital or near orbital trajectories. These launches duplicate in all respects the operational procedures.

<u>Test Objectives</u> - To finally demonstrate the entire Space Shuttle System and subsystems through the complete mission profile including rendezvous and exchange of payloads in orbit.

Considerations - Operational worldwide tracking, data acquisition, and emergency landing facilities are required.

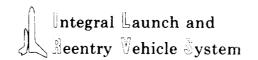
Flight Vehicle Descriptions - The three production Orbiters and two production Carriers would be used in the flight test program. The first vehicles will be rolled out during the 32nd month and fly for the first time in the 37th-38th month. The time period between rollout and fly would be used for functional and proof ground tests, and checkout for first flight. These first units are used for subsonic tests only; therefore, they need not have a complete production heat protection system and possibly would not have some of the subsystems required for vertical and orbital flight. After they have completed the contractors subsonic performance, ground handling methods evaluation, and subsystem demonstration program they would either remain in an "aircraft" configuration for customer subsonic flight test and/or crew training, or they would have the production heat protection heat protection system and missing vertical and orbital subsystems installed and be used in the early portion of the operational program.

The other flight vehicles require only three months of ground testing and checkout before their first flight. These units are "all up" production flight articles with complete subsystems installed. They would first be flown



subsonic for checkout, additional subsystem performance and crew training. After completion of this short series of Phase I tests they will be used for Phase II, and III tests, with the first flight articles acting as backup.

These flight vehicles would be turned over to the customer at the end of Phase III testing for further flight tests, crew training, or operations.



- 2.3 <u>Facilities Plan</u> Some of the assumptions and objectives used in determining facility requirements for the fabrication, assembly, ground test, flight operations and decertification of the two-stage fully reusable system included (1) maximum use of existing facilities; (2) total MDC, government and vendor testing capabilities are at the disposal of this program; (3) factory-to-pad flow; (4) minimized cost; (5) 24 hours on pad; and (6) six day recertification period. Figure 2-23 is a table which summarizes the estimated facilities requirements and Figure 2-24 shows the estimated facility availability requirement schedule. The following paragraphs briefly discuss the considerations applicable to these facilities.
- 2.3.1 <u>Manufacturing and Assembly</u> A detailed study of fabrication and assembly facilities will be required because of the size of the vehicles.

 Subassembly could be accomplished almost anywhere that there is adequate manufacturing floor space, but final assembly facilities are configuration sensitive. Final assembly location should be primarily a trade off between facility cost and the contracts resulting from recertification maintenance during recycle. Figure 2-25 summarizes the "Pros" and "Cons" of potential final assembly areas. The Corps of Engineers standard 40 ft truss height for federal buildings results in a requirement for facility modification or new facilities with adequate truss height.

The following are final assembly facility alternatives:

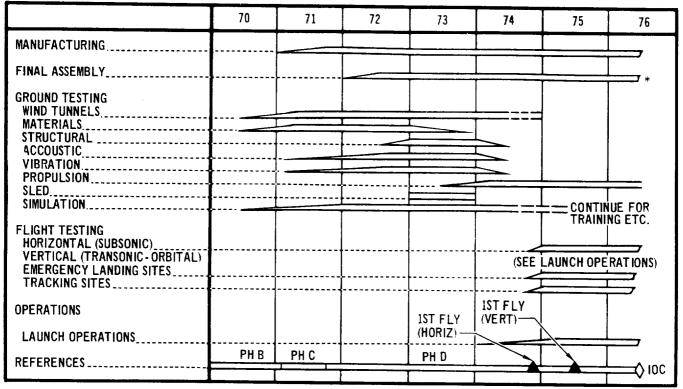
- o <u>Minimum Expenditure</u> Tulsa facility can be modified by either raising the roof or providing a trough and ramp for the required high-bay area. First flight would be made from Tulsa International.
- o <u>Minimum Schedule Interference</u> TICO facility utilization will require a new building, the use of the NASA Causeway (Orsino Rd.) and the modernization of the Titusville/Cocoa Airport or similar landing field provided by KSC. The causeway would be used in heavy maintenance during recycle.
- o Maximum use of NASA Facilities Michoud could be used as a final assembly facility by raising the roof of existing buildings or putting a trough in the building floor. This selection would use only barge transportation and first flight would be made from KSC on the airfield used for the operational phase.

FACILITY REQUIREMENTS SUMMARY

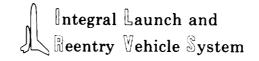
| ECT INATED | | | | | | | | | ST. TOTAL |
|----------------|----------|---|--|---|--|--|---|--|-----------------------------------|
| ECT 18 | C05T | | \$32 AIL \$32 AIL - - | Θ'' | ⊖, ¤⊖⊖ | 1 | \$50 MIL | 276 MIL 276 MIL | NOTE (1) - EST. TOTAL \$10 MRL |
| The suppose of | COMMENIS | CONSIDER FOR FINAL ASSY – MODIFY BUILDING ROOF CONSIDER FOR FINAL ASSY – MODIFY BUILDING ROOF CONSIDER FOR FARENCATION – MINIMAM MADICINATION | CONSIDER FOR FINAL ASSY - NEW BUILDING & RUNNAY CONSIDER FOR FINAL ASSY - MODIFY BUILDING & BUILD RUNNAY CONSIDER FOR FABRICATION - MINIMAL MODIFORATION NOT CONSIDERED BECAUSE OF DC-10 FABRICATION NOT CONSIDERED BECAUSE OF DC-10 FABRICATION | REYNOLDS NO & MODEL BALANCE AND SUPPORT SYSTEM MODIFICATIONS MINIMAL MODIFICATION | MDAC - LARGER SPECIMEN & SPECTRUM MODIFICATIONS MOAC - LARGER SPECIMEN & SPECTRUM MODIFICATIONS MOSEC & MIT - MODIFY SIC STANDS MOAC - MODIFY SIVR STAND MINIMAL MODIFICATION MOAC - NEW MOTION BASE SIMULATOR | EAFB FRC – HANGER & SERVICES MODIFICATIONS SKO SEE DEDFATION SUPPORT CENTER MININAL MODIFICATION MININAL MODIFICATION | KSC - PREPAD ERECTION - VAB & LAUNCH PAD MOD AND NEW RUNWAY | LOCATED DESCRIPTION - AND RELAGIONES STATIC FIRE STRUCTURE PERSONNEL, TOOLING & FIXTURE, AND GROUND SUPPORT EQUIPMENT: MINIMAL MODIFICATION MINIMAL MODIFICATION | |
| | EXISTING | | | >>>. | >> > | >> | | | |
| GOVT. | MODIFY | | > | > | > | >> | > | | |
| | NEW | | | | | | | > | |
| | EXISTING | > | · >>> | >>> | | | | | |
| MDAC | MODIFY | · >> | | > | >>> | | | | |
| | NEW | , | > | | > | | | | |
| FACILITY | | I MANUFACTURNO FINAL ASSEMBLY (ALTERNATES) TULSA PALIMDALE ST. LOUIS | TICO MICHOUD HUNTINGTON BEACH LONG BEACH SANTA MONICA | II GROUND TESTING WIND TUNNELS MATERIALS STRUCTURAL | ACCOUSTIC VIBRATION PROPULISION SLED TESTING SIMULATIONS | III FLIGHT TESTING HORIZDATAL SUBSONIC) VERTICAL (TRANSONIC-ORBITAL) EMERGENCY LANDING SITES TRACKING SITES | IV OPERATIONS (ALTERNATES) OPERATION SUPPORT CENTER | COMPLETE NEW COMPLEX EMERGENCY LANDING SITES TRACKING SITES | |

Figure 2-23 2-42

SCHEDULE - ESTIMATED FACILITY AVAILABILITY REQUIREMENTS



*SHUT DOWN DEPENDENT ON MAINTENANCE PHILOSOPHY & LOCATION



FINAL ASSEMBLY FACILITY STUDY

| FINAL ASSEMBLY | PRO | CON | | | |
|-----------------------------------|--|---|--|--|--|
| TULSA | EXISTING FACILITIES WITH NO SIGNI- FICANT ACTIVITY (DAC HAS LONG TERM LEASE) FACILITIES CAN BE MODIFIED BY RAISING ROOF OR LOWERING FLOOR GOOD LANDING STRIP — 10,000' WITH 400,000 # TWIN TANDEM OVERHAUL FACILITIES IN AREA NEAR ST. LOUIS | FACILITY MODIFICATION REQUIRED – USAF OWNERSHIP DISTANCE TO PROTO-TEST SITE REMOTE FROM SHUTTLE OPERATION FOR REFURBISHMENT POPULATED AREA ADJACENT TO RUNWAY PERSONNEL AVAILABILITY MAY BE A PROBLEM NO BARGE FACILITIES | | | |
| PALMDALE | NO SUBSTANTIAL PROGRAMS (DAC ASSIGNMENT) ADEQUATE FACILITIES FOR F/A ADDITIONAL GOVERNMENT FACILITIES AVAILABLE PRESENTLY USED BY LOCKHEED 25 MILES FROM EAFB (CLOSE TO WTR AND EAFB FOR REFURBISHMENT) UNPOPULATED AREAS | • FACILITY MOD. REQUIRED — USAF OWNERSHIP • REMOTE FROM ETR OPERATION FOR REFURBISHMENT • NO BARGE FACILITIES • REMOTE FROM ST. LOUIS • ALL-UP WEIGHT LIMITATION 245,000 ≠ ON THE AIRFIELD | | | |
| ST. LOUIS | BASE OF OPERATIONS WITH SUPPORT FACILITIES AND PERSONNEL 10,000' R/W (330,000 # TWIN TANDEM) | POPULATED AREAS ALL OVER REMOTE FROM SHUTTLE OPERATIONS FOR REFURBISHMENT OF EITHER ETR OR WTR NO BARGE FACILITIES NEW FACILITIES REQUIR TO MOST LIKELY DISTANCE TO PROTO-TEST SITE | | | |
| TICO | CLOSE TO ETR SURFACE TRANSPORTATION TO LAUNCH SITE SKILLS AVAILABLE FAVORABLE REACTION ANTICIPATED FROM NASA AVAILABLE FOR REFURBISHMENT FOR ETR OPERATIONS PROTOTYPE ASSY. COULD GO TO MSOB AND VAB | NEW FACILITY REQUIRED NEW RUNWAYS AND LANDING AIDS (ETR & TICO) REMOTE TO ST. LOUIS NO EXISTING BARGE FACILITIES | | | |
| MICHOUD | FACILITIES AVAILABLE GOOD SERVICES AVAILABLE PEOPLE AVAILABLE BARGE FACILITIES UTILIZATION OF NASA FACILITIES | REQUIRES ROOF MOD NO RUNWAY AVAILABLE REMOTE TO ST. LOUIS REMOTE FROM SHUTTLE OPERATIONS | | | |
| HUNTINGTON BEACH LONG BEACH | NOT CONSIDERED BECAUSE OF LACK OF TRANSPORTATION FACILITIES NOT CONSIDERED BECAUSE OF FABRICATION OF DC-10 | | | | |

2.3.2 <u>Ground Test</u> - It is estimated that the existing corporate and Government facilities will require very minimal (if any) modification for materials design information, structural testing of components elements and representative structural sections, and escape system sled tests.

Modification requirements which are applicable to wind tunnel facilities are shown in Figure 2-26.

The MDAC vibration and acoustic ground test facilities will require modification to enlarge their specimen and spectrum capabilities. This would include: a larger shock test machine, a 15,000 lb high acceleration shaker system, larger landing gear impact and drop test facilities, and 10,000 cubic foot acoustic test chamber facility.

Major considerations affecting the facility modification requirements for the main propulsion systems of the two stages are:

- o Because of the configuration differences between Orbiter and Carrier, and so that parallel and nonconflicting efforts will be possible for the necessary schedule adherence, separate and autonomous Orbiter and Carrier test positions will be needed. It is presently considered feasible to do Carrier development and acceptance testing at MSFC and/or MTF. For the Orbiter, similar feasibility is considered if the test position is Government furnished, since Sacramento Test Base is not considered a prime logistical location for Orbiter acceptance tests.
- o The test stands of Beta complex (S-IV-B) of our Sacramento Test Base (Calif.) are seen to offer potential for development tests.
- o Simulated hardware of less than full configuration (without wings, and fins, and other nonpropulsion system items) would be used for development testing. For acceptance testing it would be desirable to test with the full configuration, but the problems of erection and test stand mating are recognized (perhaps testing the Carrier with only one wing on and protruding from the open side of the stand can be a compromise).
- o It seems unlikely that cluster testing would be conducted on the launch pad because of difficulties in that special adaption hardware would be required between Orbiter and launch pad. As for the Carrier, study of launch pad cooling capabilities is required to determine the extent of firing that would be practical.

SUMMARY - ESTIMATED WIND TUNNEL MODIFICATION REQUIREMENTS

| DEVEL OBBENT TASK | | | | | | | EXISTING | | |
|----------------------------------|-----|---------|----------------------|---------|-----|-----|----------|--------|------------------|
| DEVELOPMENT LASA | | NIN U | KIND OF FACILITY -9- | -6- Y I | | OGW | 1,√05 | INDUST | NEW KEQUIKEMENIS |
| AERO THERMODYNAMIC | S | L | SS | 5 | HH | | | | NOTES |
| 1. LAUNCH | × | × | × | N/A | N/A | × | × | × | 1, 2, 3, 4, 5, 8 |
| 2. STAGING & ABORT SEPARATION X | × | × | × | × | N/A | × | × | × | 2, 3, 6, 7 |
| 3. ENTRY | N/A | N/A N/A | N/A | × | × | × | × | × | 8 |
| 4. TRANSITION CRUISE AND LANDING | Х | × | × | N/A | N/A | × | × | × | 1, 2, 4, 8 |

NEW REQUIREMENT NOTES

1. SPECIAL BALANCES AND DATA SYSTEMS
2. MULTIPLE BALANCES AND SUPPORT SYSTEMS
3. HIGH RESPONSE TANSDUCERS AND DATA EQUIPMENT
4. CONTINUOUS FLOW FACILITIES
5. HIGH ENTHALPY REQUIRED
6. TRAJECTORY MODEL SUPPORT WITH COMPUTER
7. HIGH TEMPERATURE JET SIMULATION

1264506786

HIGH RE FACILITY S – SUBSONIC; T – TRANSONIC; SS – SUPERSONIC; LH – LOW HYPERSONIC; HH – HIGH HYPERSONIC

Based on these considerations it is recommended that the MSFC and/or MTF SIC test stands be modified to permit either Orbiter or Carrier cluster firing tests and that the MDAC Sacramento Test Base be modified to permit Orbiter development tests. A trade study to determine the cost effectiveness of building a new runway at Michoud to support acceptance testing will be a requirement of Phase B studies.

2.3.3 <u>Flight Test</u> - Facility modification requirements for the horizontal flight test program, which is recommended to be conducted at EAFB/FRC, will be minimal. Hanger modifications and some revisions to servicing facilities will be required due to the size of the flight articles.

Modifications required at KSC to support the vertical flight tests are essentially the same as those required for launch operations and are covered in Section 2.3.4.

At this time it is anticipated that very few modifications will be required to the tracking networks and the military bases which could possibly be used for emergency landings during this phase of the program or the operations phase.

2.3.4 Operations - It is recommended that KSC be used as the vertical flight test facility as well as for program operation. The modifications required for these phases of the program are essentially the same but the occupancy need date will be established by the flight test program.

There are two modification approaches which should be considered in the Phase "B" trade studies, they are: (1) on-pad build-up, and (2) pre-pad build-up. Suggested modification in the next paragraphs are based on the assumptions that (1) the Vehicle Assembly Building (VAB) and crawler will be available, (2) vehicle quantities, 2 Carriers and 3 Orbiters maximum, (3) Carrier wing would have wing folds or splices, (4) annual launch rate of 12.

a) On-Pad Build-Up - The following modifications would be required if the VAB were utilized for payload, preflight, maintenance and turnaround activities.

Vehicle Assembly Building (VAB)

- o Transfer aisle: enlarge door openings and put in additional utility services
- o Low bay area: open up cell area and modify cranes for payload operations
- o High bay area: construct cell/transfer aisle dividing wall

Launch Pad

- o Modify basic hard stand area
- o Add new tiedown mounts
- o Add new erection devices
- o Add new mobile towers (2)
- o Modify propellant service system
- b) <u>Pre-Pad Erection</u> These modifications would be required if the high bay cell #4 is not completely activated and is used for payload, preflight, maintenance and turnaround activities.

Vehicle Assembly Building (VAB)

- o Modify transfer aisle door openings
- o Modify lower bay cell area for payload operations
- o Construct cell/transfer aisle dividing wall and remove or relocate extendable platform

Mobile Launcher/Crawler Transporter

- o Launcher umbilical tower remove majority of the swinging arms and reconfigure and relocate two of the arms
- o Launch deck: remove majority of existing equipment and modify deck in vehicle engine chamber and hold down devices

Launch Pad Area (Pad B)

o Extend services to vehicle interfaces

Landing Site

o Build new 10,000 foot instrumented runway and deservicing area.

Another alternative considered for operations was building a new facility at an Air Force Base located somewhere in mid-CONUS. This alternative could be evaluated in greater detail during the Phase "B" trade studies because of the potential secure Carrier landings within the CONUS and the many landing sites available in case of an abort situation.

- 2.4 <u>Launch Operations Plan</u> Operational techniques have been developed by performing an integrated analysis of the vehicle configurations, launch site facilities and capabilities and potential erection techniques. Two types of erection techniques were investigated, Pre-Pad and On-Pad build-up. Pre-Pad requires a large facility for vertical erection. The prime objective is to drastically reduce operational costs and complete the tasks in the shortest possible time without sacrificing excellence in performance.
- 2.4.1 Philosophy On the Mercury, Gemini, and Apollo programs vast amounts of system performance data were presented on the displays for use of the subsystem specialist at the launch site. Each generation spacecraft became more complex than its predecessor and the support manpower increased accordingly. A gross indication of the rate of increase in program launch operations costs is presented in the comparison of the launch site staffing levels required by the spacecraft contractors:

| Mercury | (McDonnell-Douglas) | 350 |
|---------|---------------------|-------|
| Gemini | (McDonnell-Douglas) | 650 |
| Apollo | (North American) | 3,000 |

On-board checkout designed to provide the flight crew with the information necessary for them to assess the performance of the system will eliminate the need for large launch test teams. The recently successful launch of the Eagle (Apollo 11-LM Ascent Stage) from the surface of the moon was accomplished through the decisions and actions of the two crewmen aboard. Only minimal consultation was made with Mission Control throughout the pre-launch preparation or launch phases. This was a giant step in the direction of autonomous operation of space vehicles. This accomplishment supports the proposed approach that spaceflight has matured to the point where it is completely within reason to rely upon the flight crew to perform launch and mission evaluation tests with minimal ground support to provide consultation and assistance in troubleshooting problems that might arise.

2.4.2 Analysis - The practice of treating the in-plant acceptance testing of spacecraft as pre-launch testing as done in the Gemini and Apollo Programs provides a "Factory to the Pad" operation which assures maximum possible efficiency of the vehicle upon arrival at the launch site. Specialized testing such as Electro-Magnetic Interference (EMI), and systems calibrations against known standards will be accomplished at the contractors plant prior to delivery. Aside from the handling and vertical erection of the vehicle, the servicing and final

system checkout necessary before launch of the spacecraft closely parallels the activities required to prepare commercial airliners for flight. Gemini and Apollo experience was heavily drawn upon in the examination of adapting current airline checkout and servicing techniques to the ILRVS. The elements of the plan are structured about the use of on-board checkout and minimal support from the ground. It will be necessary to greatly simplify the Ground Support Equipment (GSE) and the handling and servicing techniques in order to make it possible to complete the required tasks in the short time periods. Relaxation of the exactness of the volumes of the propellants loaded for flight will also help in meeting these reduced servicing times.

Ground turnaround and launch preparation are structured to provide the shortest on-pad time possible. Retaining the vehicles in a horizontal position enhances the access to the craft and reduces the possibility of weather damage to the vehicle. Installation of the cargo module after the completion of the maintenance and checkout cycle and just before moving the vehicles to the pad reduces the probability of changing out the cargo due to late mission changes. The pad activities are limited to those tasks that can not possibly be performed in advance of moving from the maintenance area.

Prime operational objectives are to be able to launch within one day after leaving the maintenance facility and to be able to withhold cryogenic propellant servicing until T-2 hours. Figure 2-27 shows the activities occurring at the pad from the time the vehicles leave the maintenance area until the launch. A cursory study has been made using Saturn V information, which indicates that it is possible to achieve these objectives. The study was made considering that all cryogenic servicing preparation steps such as bulk-head purge by use of helium (if required) and GSE servicing lines chill-down had been accomplished and the ground system was ready to start delivery of the propellants. It is also necessary to depart from the standard Saturn V techniques of serially servicing the stages with LOX first and then servicing the LH₂. To meet the time objective it will be necessary to consider loading both stages simultaneously and with LOX and LH₂ flowing concurrently. A 15 minute pre-cool to condition transfer lines

ON-PAD BUILDUP TECHNIQUE

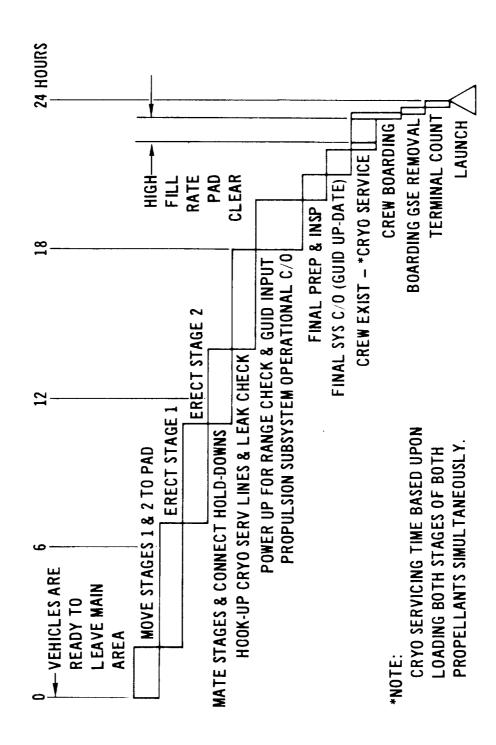


Figure 2-27

and tankage, prior to filling operations, is allowed for each system. The practice of slow filling (2000 GPM) during the periods from 0-5% and 95-100% of the loading operation has been considered. Fast fill rates of approximately 14,000 GPM and 10,000 GPM for LH_2 and LOX respectively, will be required. An LH_2 fast fill rate of approximately 10,000 GPM can be utilized by limiting LH_2 slow fill to the 0-2% and 98-100% portion of the loading operation.

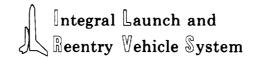
In the interest of safety, it is considered that the crew leave the vehicle just prior to the start of servicing propellants. They re-enter during the final phase of servicing, at which time LOX loading is completed and only LH $_2$ low-rate filling is in operational.

Based on experience from previous programs, it appears feasible to accomplish the objectives of the Launch Operations Plan. However, a detailed trade study with finite operational characteristics of the airborne and ground equipment must be made in Phase B to attest to the validity and cost effectiveness of the plan.

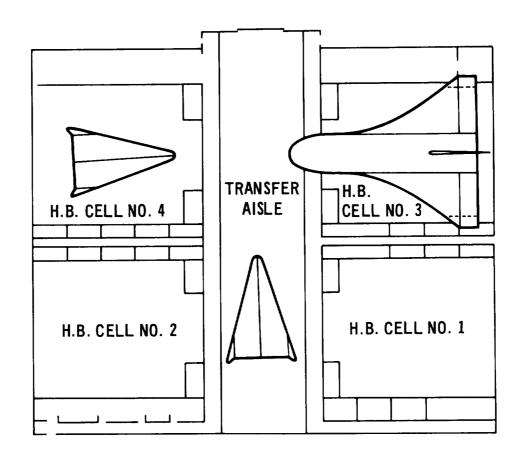
2.4.3 Erection Techniques - Two techniques are considered feasible for erection of the vehicles. Each of these techniques will require some degree of facility modification. The techniques are identified as: 1) Pre-Pad in which the vehicles are integrated vertically in the Vertical Assembly Building (VAB) and utilizing the Launch Umbilical Tower (LUT) prior to movement to the pad. For the On-Pad concept the vehicles are transported horizontally to the launch pad where erection and integration are accomplished.

Using the Pre-Pad techniques would require a large facility for vertical erection. The VAB at the Kennedy Spacecraft Center could meet the requirements for both the ground-turnaround cycle and vertical erection with a limited amount of building modification. For the On-Pad buildup technique, a new erector for each vehicle is required. Requirements for facility modification are discussed in section 2.4.5.

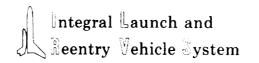
- Pre-Pad Buildup This technique requires a facility with sufficient ceiling height and crane capability to translate each vehicle from the horizontal to vertical position. (Refer to Figures 2-28 through 2-32.) The Carrier and Orbiter would proceed horizontally through the buildup and checkout individually. The Carrier would be the first element to the erected. First, the Carrier is backed out of the cell, the lift crane attached, and the tail section attached to a dolly. As the vehicle is erected the dolly moves forward into the cell. When fully erected the dolly would be disconnected and the Carrier elevated. As the Carrier is elevated vertically the launcher unit is moved into the cell and the vehicle is lowered onto the launch moment and secured. Concurrent with securing the first stage, the second stage, with payload installed in an adjacent area, will proceed through vertical erection and mated to the Carrier. After mating, the vehicle system would be checked for system compatibility and partial servicing would be accomplished. The system can then be put in a stand-by mode or transported to the launch pad area. During the stand-by period changes in equipment or payload could be readily made within the VAB.
- b) On-Pad Buildup For this technique the Carrier and Orbiter vehicles would be individually moved in the horizontal position from the low bay hangar to the launch pad area as shown in Figures 2-33 and 2-34. First, the Carrier is backed into position adjacent to the launch mount. The vehicle would be disconnected and the erection device connected to the vehicle carriage after which it is raised to the vertical position and secured to a launch deck fixture. Next, the Orbiter would be positioned for erection by bringing it nose first over the Orbiter erection device. Erection is accomplished in a manner similar to that for the Carrier and the two vehicles are mated. The final step is the implacement of two service towers for system and servicing connections as well as crew loading. These towers would additionally provide rapid crew egress. After the system functional checks and servicing operations are performed, crew and passenger boarding would be accomplished and launch countdown started.
- 2.4.4 <u>Launch Operations</u> The launch operations philosophy used in determining this concept was to reduce operating costs and complete the required tasks in



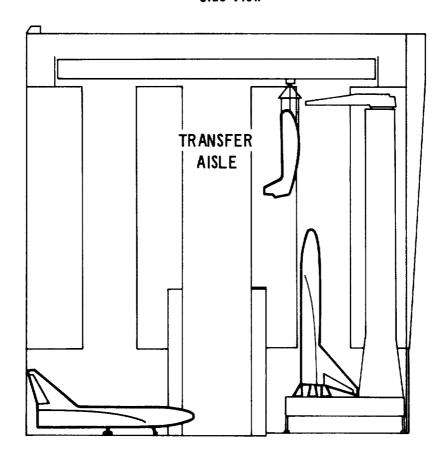
VAB UTILIZATION Plan View — Vehicle Horizontal



1LRVS-312F



VAB UTILIZATION Side View



1LRVS-315F

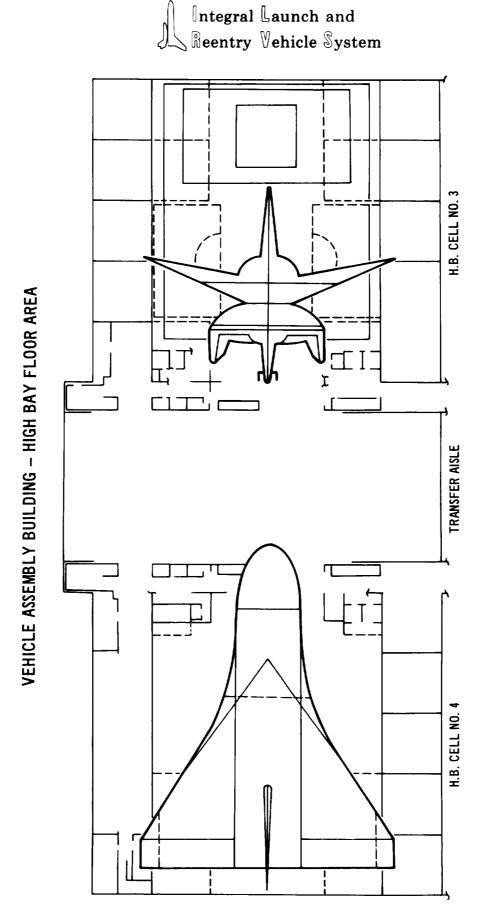
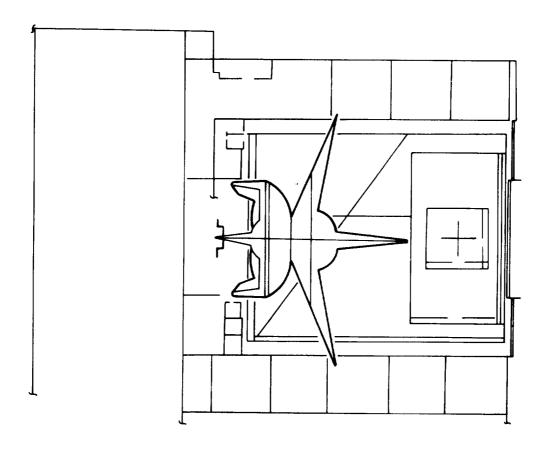
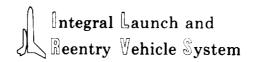


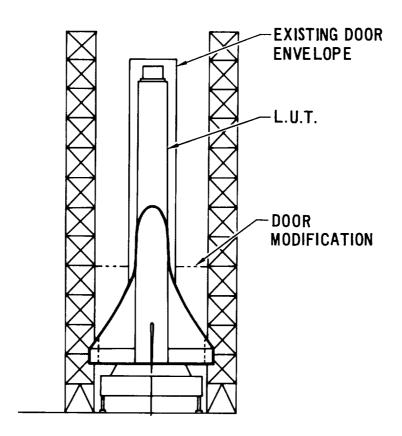
Figure 2-30

V.A.B. HIGH BAY CELL - FLOOR LEVEL

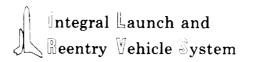




VAB UTILIZATION High Bay — Side View

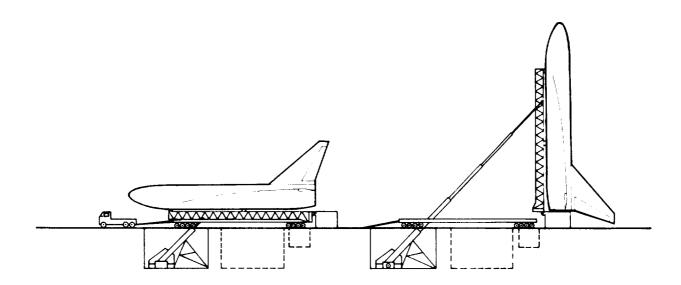


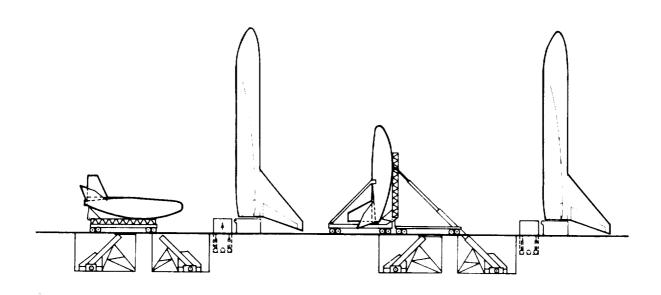
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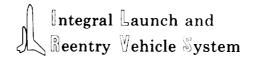


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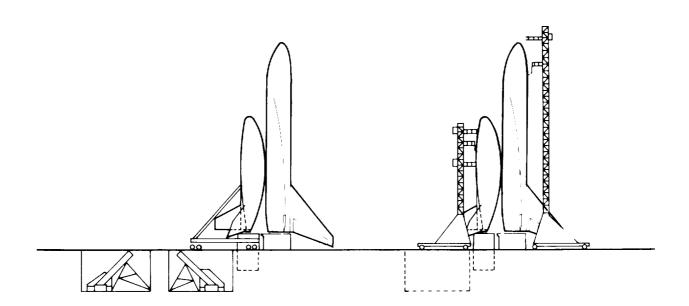
PAD ERECTION TECHNIQUES

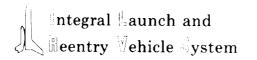






PAD ERECTION TECHNIQUES (Continued)





the shortest period of time without sacrificing excellence in performance. It is based on experience acquired from previous space programs. The modes of operation outlined below will, when implemented, assist in realizing the goal of reduced operating costs and reduced time on the pad.

- a) Factory Final Assembly Factory final assembly consists of those tests conducted by manufacturing and comprise the final manufacturing buy-off. The prime purpose of these activities is to assure static integrity of the fluid and gas systems prior to starting factory acceptance checkout. Each vehicle will be assembled to completion (less servicing) during factory final assembly.
- b) Factory Acceptance Checkout Factory acceptance checkout is to be treated as pre-launch testing. This provides a "Factory to Pad" operation which assumes maximum possible efficiency of the vehicles upon arrival at the launch site. Component level, detail subsystem, and total system checkout will be performed as part of the factory acceptance checkout phase. Any specialized testing such as electromagnetic compatibility (EMC) will also be accomplished during this phase. Checkout must be a comprehensive, in-depth penetration into all possible problem areas. Also, design deficiencies, manufacturing discrepancies and equipment malfunctions must be detected and corrected. Interface simulators will be utilized during this phase to eliminate problems at the launch site during mating of the stages.
- o <u>Component Testing</u> Individual components will be thoroughly tested and checked out prior to installation. Majority of the component tests will be done by the vendor, prior to shipment, utilizing his specialized test equipment, personnel, and facilities. All testing and calibrations performed by the vendors will be done in accordance with approved specifications. Equipment functional checks (EFC) will be performed by the contractor on components prior to their installation into the vehicles. An EFC is a test whereby components are verified for a correct indication or response due to a known input. These pre-installation tests should also be performed on spares periodically. Electrical wiring will be thoroughly checked and verified prior to installation.

- Subsystem Testing Not all checkout/testing can be accomplished with on-board equipment. Mechanical subsystem verification such as leak detection, for example, require techniques that are not adaptable to on-board checkout systems (OCS). However, once a mechanical subsystem is verified, OCS can be utilized to monitor and/or track the subsystem behavior or its characteristics. Of all vehicle testing, subsystem testing will require the major amount of ground support equipment (GSE). It is likely that a ground computer system of some reasonable capacity will be needed for subsystem testing. Initially, subsystems may tie into the ground computer with a hard-line link, at least for calibration purposes. A telemetry ground station for instrumentation calibration and verification and an RF ground station for uplink commands will also be required. The on-board computer, depending on its sizing could serve to greatly reduce requirements on the ground computer system by the use of internal stored program control. When the initial calibration of sensors has been established and proper operations of certain subsystems (i.e. power, telemetry, etc.) are verified with use of GSE, then the OCS can be utilized to complete subsystem testing. Interface simulators will be designed to operate with the OCS so that testing performed during factory acceptance checkout resembles launch site testing and actual flight activities. This will also help to checkout the on-board and ground computer systems software.
- o <u>System Testing</u> Systems testing will be accomplished primarily using on-board controls, displays, and OCS. It will closely parallel the activities required to prepare commercial or military aircraft for flight. A minimum amount of specialized GSE will be required to support this phase of testing.
- c) Pre-Pad Technique Pre-Pad testing will be accomplished primarily using on-board controls, displays, and OCS. Proven software and procedures, verified during subsystem and system testing at the contractors facilities, will be utilized. The vehicles will be erected and mated on the mobile launcher in the facility as shown in Figures 2-28 through 2-32. Because of the utilization of interface simulators at the contractor facilities interface checks prior to mating of the vehicles will not be required.

The use of OCS eliminates the need for many external umbilicals. Those that are required are mainly for servicing, propellant loading, and for ground power and communications. These umbilical lines are to be hooked-up and checked-out from the vehicle interfaces, through the launcher umbilical tower (LUT), to the facility interfaces. Mechanical and electrical interfaces of the two vehicles will be verified followed by a combined systems test (CST). Servicing of oxygen, food, and water will be accomplished. Cargo will be loaded in the orbiter and the mated flight vehicle and mobile launcher then transported to the launch area (Pre-pad technique).

d) Pad Technique - Pad tasks will be limited to those tasks that cannot possibly be performed in advance of moving the vehicles to the launch complex. The launch schedule is structured to provide the shortest on-pad time possible. Figure 2-27, which shows the schedule for pad activities, is for on-pad erection. For Pre-Pad buildup the basic schedule differences would be the transport, tie-down and service connection times. After vehicle mating, pad activities start with hookup of the umibilical lines at the base level of the LUT, and leak checking of the fluid and gas connections. Power-up checks will be made and vehicle/range compatibility test performed utilizing OCS. The flight vehicle landing propulsion systems will be fueled (with JP-4) and final launch preparations and inspection tasks accomplished. Final launch count will begin with servicing of the cryogenic systems. After servicing is completed, umbilicals will be disconnected from the flight vehicles.

NOTE: To meet the time objective, it will be necessary to load both vehicles simultaneously and with LOX and LH2 flowing concurrently.

Crew and passengers will ingress and a final systems checkout using OCS will be performed to insure a flight ready condition. The pilot will then initiate ignition of the boost propulsion systems and determine if sufficient engine and thrust is available. The pilot will then initiate lift-off much in the same manner as aircraft pilots do on refusal speeds on take-off.

2.4.5 <u>Facilities Analysis</u> - A cursory examination of the existing launch facilities which could be considered for the space shuttle operation has been made. No attempt was made to determine the planned usages of these facilities during the time phasing of the shuttle system, but rather that it is feasible to consider their use for launch. Complexes 34 and 37 used for launching Saturn IB vehicles weighing 1.3 million lbs. would require extensive modification to make them of use on the space shuttle program. Complex 39 offers the greatest advantage. The Vertical Assembly Bldg. (VAB) can be used as the maintenance area. The Orbiter will fit in the building in a horizontal position in either the low bay area or the high bay cells. The Carrier will fit in a high bay cell in a nose-in manner. A detailed study will be performed in Phase B to determine detail facility criteria.

Retaining the vehicles in a horizontal position until just prior to launch enhances the access to the craft. The launch pad schedule (on-pad technique) is structured to limit the tasks to those that can not possibly be performed in advance of moving to the pad. Vehicle erection, final system checkout, cryogenic servicing, crew boarding and launch will be performed on the pad. Several methods of erecting the vehicle from the horizontal to vertical position have been investigated.

One method worth further consideration is that of using the existing 250 ton crane in the high bay area to rotate the vehicle and subsequently position it on a portable launch platform, possibly the existing Launch Umbilical Tower (LUT). The existing Crawler-Transporter would be used to move the vehicle to the launch pad.

Advantages

- o Maximum use of existing facilities.
- o Vehicles can be checked out in mated condition before going to the pad.
- o No erector required.

Disadvantages

o Field splice of wing type required to enter high bay cell.

Another possibility is to tow the vehicles to the pad on their own landing gear and use an erector to position the craft vertically.

Advantages

- o No need for VAB and 250 ton crane for erection.
- o No need for LUT or Transporter-Crawler.

Disadvantages

- o No chance to checkout vehicles mated until erected on pad.
- o Requires new erector and tower structure.

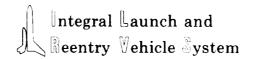
Detail trade studies performed during Phase B would provide the information necessary to make a decision between the two approaches. Programmatic interface with other programs was not analyzed during this study. These does not appear to be a significant advantage of one approach over the other with respect to the time required to perform the tasks necessary for launch. However, on pad erection would minimize facility interference with ongoing programs.

In any case, there is a great deal of merit in considering the VAB for the maintenance area and Complex 39A or B pads for the launch. In particular, the existing large storage facilities for LH₂ (850,000 Gals.) and LOX (950,000 Gals.) adjacent to the pad would be a significant cost advantage to the program.

The remaining major facility necessary to complete a centralized operations complex is a landing strip. The Cape Skid Strip can be used, but there are many problems of clearances to be resolved in moving overland to the Maintenance Facility. If a path is cleared from the west end of the Skid Strip to take advantage of barge transportation, there is not enough clearance to go through the NASA Causeway bridge. To go overland to the north side of the Causeway entails a highly dense industrial area. Another approach is to locate a runway parallel to Kennedy Parkway with runs North/South adjacent to the VAB. An interesting thought is to consider pouring concrete in the garden part of the Kennedy Parkway and upgrading the existing road into a runway which would be closed off to motor traffic during landings.

- 2.4.6 <u>Ground Support Equipment (GSE) Requirements</u> The following is a preliminary listing of major items and categories of GSE which will be required to support the Launch and Post Flight Operations. A description of some of the handling and servicing GSE is also included.
 - 1. Prime Mover (TUG)
 - 2. Electrical Power External
 - 3. Hydraulic Power External
 - 4. Pneumatic Service External
 - 5. EC/LSS Service External
 - 6. Galley Servicing Equipment
 - 7. Sanitation Servicing Equipment

- 8. Engine Service Kits
- 9. Vehicle Access Equipment
- 10. Lubrication Equipment
- 11. Purge Equipment
- 12. Safety Equipment
- 13. Propellant Serving Equipment
- 14. Erection and Mating Equipment
- 15. Cargo (Canister) Loading Equipment
- 16. Cargo (Canister) Transport Equipment
- 17. Rigging Equipment
- 18. Ground Telemetry Station
- 19. Ground Communication Station
- 20. Automatic Checkout Equipment
- 21. Pyrotechnic Handling and Checkout Equipment
- 22. System De-contamination and Cleaning Equipment
- a) Prime Mover The prime mover (tug) shall provide the power for ground movement (towing) of the horizontal flight vehicle when supported by its landing gear. The prime mover will interface with the flight vehicle via the towbar. The prime mover may be required to furnish the following auxiliary functions to the flight vehicle:
- o Communications via hardwire intercom
- o Electrical power external
- o Services-external (hydraulic, pneumatic, etc. for braking, steering, etc.)
- b) Electrical Power External External electrical power will be required to support the flight vehicles and passenger payload canisters at the launch pad and at the maintenance and service areas. Limited external electrical power may be required during horizontal flight vehicle towing operations. Power is required to activate control and monitor functions and to operate dependent systems.
- c) <u>Hydraulic Power</u> External External hydraulic power will be required for the flight vehicles at the launch pad, and at the maintenance and service areas. Limited external hydraulic power may be required during horizontal flight vehicle towing operations. The flight vehicle requires



hydraulic power to operate the primary and secondary aerodynamic flight control surfaces, wheel brakes, ground steering, landing gear actuation, rocket engine gimbaling, and turbojet engine deployment. The external hydraulic power unit shall have the capability to fill, bleed, pressurize and remove contamination from the onboard system. Capability shall also exist to pneumatically charge the pneumatic side of the flight accumulators and reservoirs.

- d) Pneumatic Service External External pneumatic service will be required to support the flight vehicles at the launch pad, and at the maintenance and service areas. Limited external pneumatic service may be required during flight vehicle horizontal towing operations. The flight vehicles require pneumatic support for propellant and oxidizer tank pressurization, rocket engine purges, insulation purges, equipment and cargo bay purges and pressure for pneumatic powered units. For ground operation, ambient temperature gas can be delivered to the vehicle. For flight, the onboard tanks will be charged with cold high pressure gas or cryogenics where feasible. Primary gases will be helium and nitrogen. Missile-grade air may be acceptable for some ground operations.
- e) EC/LSS (Environmental Control/Life Support System) Service External The flight vehicles and passenger payload canister will require external EC/LSS support and servicing. The flight crew, passengers, onboard avionics and hydraulics will be dependent on the EC/LSS. The following consumables will require servicing for each mission: LH₂, LOX, LN₂, Freon 22 and potable H₂O. The system will require periodic coolant fluid service. During launch operations and some checkout and servicing operations, the EC/LSS will reject heat via the onboard GSE heat exchanger to external supplied coolant.
- f) <u>Galley Servicing Equipment</u> Galley servicing support equipment will be required to perform preflight and postflight servicing operations of the flight hardware. These services will be required for the Orbiter vehicle and Passenger Payload Canister. The servicing will primarily consist of replenishment of eatable consumables, replenishment of equipment consumables, and galley cleaning.
- g) Sanitation Servicing Equipment Sanitation servicing support equipment

will be required to perform post flight and preflight servicing operations of the flight hardware. The Carrier vehicle will require only standard janitorial type maintenance. The Orbiter vehicle and the Passenger Payload Canister will specifically require food waste disposal, human waste disposal, and spent expendable supplies and packaging disposal. Prior to flight, it will be necessary to reprovision the onboard consumables.

- h) Boost and Turbojet Engine Service Kits The boost and turbojet engine service kits will consist of all the support equipment required to service and maintain the turbojet, main propulsion and attitude control rocket engines. It will include but not be limited to the following:
 - A. Engine dollies and stands
 - B. Engine shipping containers
 - C. Engine slings
 - D. Engine plugs and covers
 - E. Engine rigging and calibration instruments
 - F. Engine tools special
- i) <u>Vehicle Personnel Access Equipment</u> Vehicle personnel access equipment will be required for flight crew, passengers, and maintenance personnel for access and egress to and from the flight vehicles. Because launch operations are vertically oriented and landing and maintenance operations horizontally oriented, access equipment configurations must be compatible with both flight vehicle orientations. Horizontal access equipment will be predominately mobile equipment. Vertical access equipment will primarily be associated with the launcher.
- j) Propellant Servicing Equipment Propellant servicing equipment will be required to support loading operation of flight vehicle cryogenic propellants and turbojet engine fuel. This equipment will include tank supply trucks, pumps, subcoolers, flow monitoring and control equipment and associated transfer hoses. Automatic features will be designed into the servicing equipment wherever possible to simplify vehicle loading and aid in meeting the servicing timeline. A study will be made to determine where existing propellant handling equipment can be utilized, in view of the extremely high flow rates required.

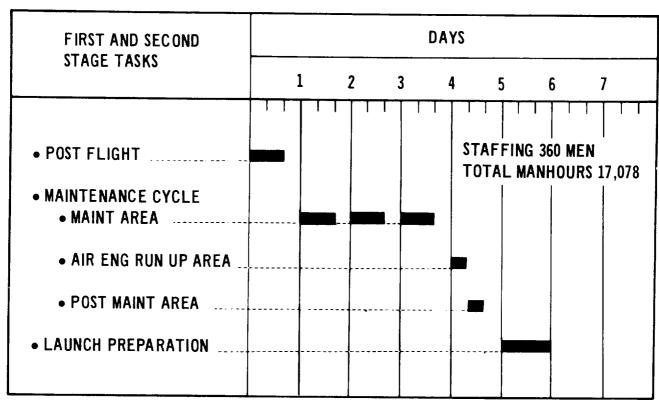
2.5 <u>Maintenance Plan</u> - Based on the results of a maintenance analysis conducted as part of the special emphasis study on Ground Turnaround and reported in Volume II of this report, this plan identifies maintenance requirements and procedures necessary for the turnaround of the Carrier and Orbiter.

The turnaround cycle is accomplished in three phases: (1) Post Flight Maintenance; (2) Maintenance Cycle; and (3) Launch Preparation. The time to perform the three phases of turnaround is illustrated in Figure 2-35. All vehicle maintenance is performed at the launch site. Scheduling the maintenance is a key to minimizing the turnaround cycle time. Turnaround activities at the launch site consist of scheduled and unscheduled maintenance and servicing in support of the three phases. Scheduled maintenance should be accomplished as a pre-planned function of Maintenance Control and timelined into a combined systems operation and programmed for performance on a non-interference basis. This type of maintenance normally consists of visual inspection, servicing and deservicing, payload installation and removal, limited functional checks and corrosion control. Unscheduled maintenance of the spacecraft consists of removal and replacement and repair.

- 2.5.1 <u>Scope</u> This Maintenance Plan establishes the requirements and utilization of maintenance resources. The types of maintenance, levels, personnel management procedures and facilities necessary to satisfactorily perform the turnaround cycle are identified.
- 2.5.2 Maintenance Philosophy A prime contributing factor to the attainment of the 6-day turnaround period is the philosophy that minimum maintenance will be performed at the launch site. Maintenance will be minimized by inspecting the vehicle subsystem components, repairing, removing and replacing only equipment that has malfunctioned or will exceed its useful life limit before the completion of the next mission. The vehicle design aids in achieving the goal of removing and replacing a line replaceable unit (LRU) within 15 minutes. Calibration and alignment procedures will be accomplished on an LRU while installed if procedures do not exceed 15 minutes. When calibration of an LRU requires more than 15 minutes, the unit will be removed and replaced with a calibrated unit. The removed LRU will be sent to the Precision Measurement Equipment Laboratory (PMEL) for calibration. Onboard checkout provides subsystem go/no-go condition, fault isolation and inflight monitoring of critical parameters. The onboard checkout

REPORT NO. MDC E0049 NOVEMBER 1969

MINIMUM TURNAROUND SUMMARY



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(OCS) System will test replaced units during maintenance to ensure operational status. This concept is effective in that the replaced unit is tested in place, eliminating the need for duplicated Aerospace Ground Equipment (AGE), additional maintenance personnel and facilities. When a subsystem is not compatible with the onboard checkout approach required to test subsystems to the (blackbox) level, necessary testing equipment will be provided at the Maintenance Area. However, testing required below this level (e.g., repairs, modifications, build-up, alignments and calibrations) as a result of repairs, will be accomplished at the manufacturer's facility. In addition, the manufacturer is responsible for the performance of failure analyses to determine when a trend exists. Appropriate attention is then directed to correct the defect. When repairs and testing are completed, the components will enter the supply system as a ready-for-use item.

2.5.3 Facilities Requirements

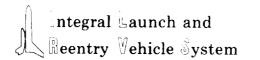
- a) A servicing and deservicing area is provided to perform post-flight maintenance that requires immediate attention, such as, off-loading of liquids and gases and payload removal (orbiter).
- b) Upon completion of post-flight maintenance, the spacecraft is moved to the Maintenance Area where the scheduled and unscheduled maintenance is performed. The Maintenance Control Section, which directs all maintenance, is centrally located within the Maintenance Area. Maintenance Control will be discussed in detail in Paragraph 2.5.6.
- c) An area is provided to run up the air breathing engines, perform subsystem confidence testing on which maintenance has been performed, operationally check all critical subsystems and JP fuel servicing. Following subsystem operational certification, the spacecraft is towed to the Post Maintenance Area. This area is designed to provide facilities to allow the performance of the maintenance for special tasks. The air breathing engine bearings, seals, gears, and lubricating subsystems are flushed, purged, dried and dry lubricant applied to satisfy initial engine start-up following ascent and orbital storage (orbiter only). In addition to the air breathing engine maintenance tasks, the payload is installed, and the spacecraft is mounted on the erection dolly.

2.5.4 Types of Maintenance

- a) <u>Scheduled Maintenance</u> consists of calibration, inspection, alignment, and replacement of life-limited items. Two types of scheduled maintenance are required:
- o Operational scheduled maintenance is that requirement imposed on installed equipment to assure a constant operational status.
- o Stored scheduled maintenance is that requirement imposed on items in storage where such items must be retained in a ready-for-issue status.
- b) <u>Unscheduled Maintenance</u> consists of repair or removal and replacement of components required to return a subsystem to an operational status.

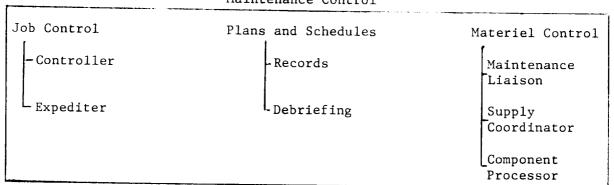
2.5.5 Maintenance Planning

- a) Maintenance shall be programmed and planned through an integrated logistic support effort encompassing spares, facilities, scheduled and unscheduled maintenance, modifications, maintenance procedures, transportation and packaging. In order to minimize launch pad operations, servicing (e.g., gaseous oxygen, water, etc.), will be accomplished in the Post Maintenance Area. Interfaces with associated subcontractors shall be established to coordinate the planning and performance of maintenance activities.
- b) In conjunction with the Development and Operation phase system engineering effort, a maintenance analysis shall be conducted to provide documented data for maintaining Aerospace Vehicle Equipment (AVE) and Aerospace Ground Equipment (AGE). Data will be required in two forms:
- o AVE Preventive Maintenance Requirements Summary
- o AGE Preventive Maintenance Requirements Summary
- c) A systematic method of maintenance reporting shall be required to establish a bank of maintenance data. The data will be used to establish trends, identify potential problem areas, and provide historical records for related maintenance activities.
- 2.5.6 Maintenance Management Procedures The maintenance control organization plans, schedules, and controls all maintenance. This organization schedules maintenance workloads, processes material transactions and dispatches parts, materials, specialists and AGE to requiring activities. To satisfy these requirements, Maintenance Control is functionally organized into Plans and Schedules, Job Control, and Materiel Control as indicated in Table 2-1. Following



each flight, the debriefing portion of Plans and Schedules questions the flight crew on all subsystems that have not functioned satisfactorily to determine what

Table 2-1
Maintenance Control



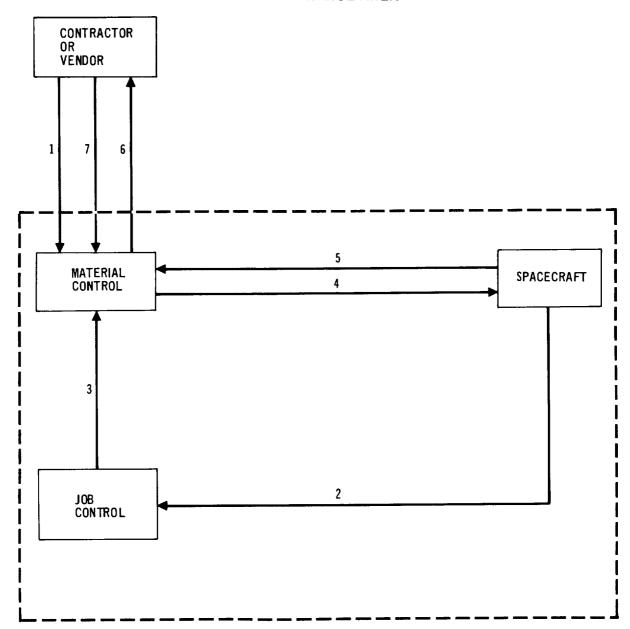
discrepancies may exist. Plans and Schedules gathers debriefing reports, reviews Quality Assurance inspection reports, and the data supplied by the onboard checkout equipment. With this information and known scheduled maintenance, (e.g., life-limited items, airframe and engine changes), Plans and Schedules develops a maintenance plan for each vehicle as it enters the maintenance cycle. This plan is then put into a schedule of specific actions and executed by Job Control. Job Control accomplishes this task by dispatching the necessary components and specialists, monitoring the progress and taking action on problems not foreseen in the original maintenace plan.

Materiel Control will assure that spacecraft spares are available to the maintenance activities in the required quantities at the proper time so that the maintenance schedule can be met. In addition, Materiel Control receives, stores, issues and processes items requiring maintenance prior to shipment to respective manufacturers. All components removed from the spacecraft because of life-limited requirements or malfunction must pass through Materiel Control for processing.

A sequence of events for processing a component is shown in Figure 2-36. A component prior to shipment from the manufacturer is thoroughly tested and shipped to Materiel Control at the Maintenance Area where it will remain in ready-for-issue storage until needed. During the maintenance cycle, if a technician discovers a malfunctioning component on the spacecraft, he notifies Job Control of the malfunction. Job Control notifies Materiel Control to make ready a replacement component for spacecraft installation, and dispatches a specialist to clear the



MAINTENANCE AREA



malfunction. The specialist who discovered the malfunction will remove the component while the specialist dispatched will pick up the ready-for-issue component at Materiel Control, install it in the spacecraft, and give it an operational check utilizing onboard checkout. The removed component is taken to Materiel Control where it is processed and shipped to the manufacturer for repairs and recertification testing.

The manufacturer, upon being notified that a component is required for space-craft installation, ships a ready-for-issue component to Materiel Control before the removed component reaches the manufacturer, thereby, providing Materiel Control with optimum spares availability.

Maintenance at the manufacturer's site consists of those activities required to support pre-delivery tests and the ground turnaround cycle. Schedules and procedures shall be required to accomplish test, repair, overhaul and modifications of spacecraft subsystem components and support equipment.

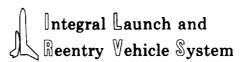
The Maintenance Base is responsible for all manufacturer maintenance activities, including those in which actual performance is a function of the manufacturers.

Repair and Modification - The maintenance organization will maintain surveillance of all components processed through the manufacturers repair cycle, and conduct on-site surveys, when required, to assist the manufacturer in accelerating the processing of repairs.

The manufacturer's maintenance data shall be continuously evaluated, and changes in procedures recommended, as necessary, to provide optimum support.

Inspection - The integrity of the structure and thermal protection system should be certified periodically to insure safety and reliability in future missions. The maintenance plan requirements are such that every possible time saving effort should be considered which would reduce periodic inspection and turnaround time. This requires inclusion of an effective nondestructive inspection (NDI) program. During the definition phase candidate NDI techniques should be evaluated by application to advanced material technology programs. Critical areas of the system should be identified and provisions made for application of suitable NDI techniques. Possible techniques include:

- o Radiographic inspection, including neutron radiography
- o Ultrasonic inspection
- o Microwave inspection for non-metallic materials



REPORT NO. MDC E0049 NOVEMBER 1969

- o Electromagnetic inspection (eddy currents)
- o Acoustic impact inspection

Applicability to scale-up and possibilities for automatic scanning to provide rapid testing of large areas should be a prime consideration in evaluation and selection of NDI techniques.

2.6 Vehicle Recovery Plan

- 2.6.1 <u>Summary</u> Based on the operational philosophy adapted for the Space Shuttle System, recovery or landing requirements were considered for the normal mode at the intended landing site and possible abort situations considering the nominal 55° inclination launch. In addition, a possible mid-CONUS launch site with its abort recovery sites was considered and is discussed in this section.
- 2.6.2 Philosophy The design and operational approach assumed is similar to airline and military aircraft inasmuch as: (a) both stages of the system will be maintained utilizing large aircraft techniques; (b) the carrier vehicle has the capability to fly back to the launch site for a normal horizontal approach and landing; and (c) the orbiter, with once-a-day return from orbit capability and entry maneuverability, also returns to the launch site for a horizontal approach and landing. Personnel safety and spacecraft integrity are prime objectives, achieved through multiple redundancy, mission success with one main engine inoperative during ascent in both stages, fail operational/fail safe for all mechanical systems, fail operational (twice)/fail safe for avionics systems; hold down capability prior to liftoff; on pad quick egress system; and intact abort capability during all mission phases.
- 2.6.3 Normal Recovery Requirements The selected landing site, ETR, will be capable of handling the vehicles on normal and emergency approach and landing. Navigational, tracking and landing aids are available to direct and land the vehicles in minimum weather. Fire and crash equipment will be available and provided as necessary. Selected alternate landing sites will be equipped with comparable facilities. The following list contains the requirements and capabilities for the selected recovery or landing area:
 - a) Runway 10,000 foot long strip with a load capacity of 500,000 pounds at a 3-4 "G" impact with the designed landing gear. Barrier device at each end of runway to prevent overrun. Lights to support night or minimum weather landing.
 - b) Taxiways Located at each end of runway and routed to the turnaround area. Support 500,000 pounds. The required turning radius from the runway to the taxiways has not been defined at this time.
 - c) <u>Landing Aids</u> Radar installed to provide the capability of approach and precision surveillance (PAR). ILS provided with strobe lights to support minimum weather approach and landing.

- d) Navigational Aids TACAN provided.
- e) <u>Control Tower</u> Tower provided to assist the vehicle on approach, landing and takeoff. Weather information available from the installed weather station or by communication.
- f) <u>Communications</u> Compatible equipment provided to allow two-way communication between the control tower and the Orbiter and Carrier.
- g) <u>Fire Fighting</u> Fire trucks and helicopters provided with required fire fighting chemicals. The fire fighters and crash crew are equipped to provide a lifting device for the vehicle if a gear-up landing is encountered. Medical assistance standing by to be used as required.

Post landing requirements for accomplishing post flight maintenance, scheduled and unscheduled maintenance and launch preparation are not included in this section.

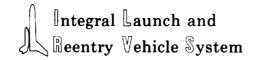
- 2.6.4 Abort Recovery Requirements For the nominal 55° inclination launch to the southeast, the ground track passes over potential recovery sites that can be used in the event of an abort of either vehicle during ascent and separation phases. These recovery landing sites include Great Exuma Island and Long Island, both in the Bahamas, and Puerto Rico. Any site selected for abort recovery would require those capabilities listed in the preceding paragraph for the normal recovery area to assure a safe landing. The following equipment would be required to support the turnaround of either vehicle in preparation for the ferry flight back to the launch site:
 - a) <u>Tugs (Tow Motors)</u> Tugs with tow bars compatible to the nose landing gear of both stages provided for ground handling.
 - b) Servicing Equipment Units available to service JP-4, oil and 02 to the vehicle. Deservicing equipment available to deservice, purge and pad the propulsion systems.
 - c) <u>Cooling Equipment</u> Equipment and stands provided to assist in vehicle cool down after landing.
 - d) <u>Stands</u> Egress and ingress stands utilized for flight and maintenance crews. Additional stands available to assist servicing and turnaround of vehicles for flight.
 - e) <u>Ground Power</u> Units available to provide required electrical power and pneumatic pressure for engine start.
 - f) <u>Vehicle Generators</u> Vehicle generators on hand to be installed on 2nd stage to provide electrical power for ferry flight.

- g) Payload Handling Hoisting equipment available to remove the payload and install the "Buddy" JP-4 fuel tank in the payload cavity of the orbiter.
- h) Orbiter Wing Kit A "strap-on" wing and airbreathing propulsion system to be integrated into the Orbiter for horizontal takeoff and subsonic ferry capability.
- i) <u>Crews</u> Trained personnel to maintain and inspect the vehicles to affect prompt turnaround.

During each mission a designated task group comprised of qualified personnel from the launch complex shall be on a standby status during launch through recovery. In the event of an emergency landing the task group will be airlifted to the abort site with necessary spares, tools and ground equipment (AGE). The airlifted spares would be limited to those items necessary to ready the vehicle for a one-time ferry flight to the launch site. In addition to available AGE at the recovery site, special AGE such as air breathing engine handling equipment, dollies, jacks, adapters, and other equipment needed to install airlifted spares will accompany the task group. After the spacecraft is repaired, tested, serviced, and preflighted, it will be ferried to the launch site where extensive maintenance and analyses will be performed to determine the cause of the abort. The task group will return to the launch complex and assume regular duties.

2.6.5 Alternate Launch and Abort Site - The possibility of using an existing mid-CONUS base as a launch site was investigated and shown in Figure 2-37.

Assuming a launch site such as McConnell AFB in southeastern Kansas, the Carrier vehicle could land at a number of established military or commercial bases for most launch azimuths rather than pay the weight penalty for cruise capability back to the launch site. Thus, both normal and aborted-flight landings would be accomplished away from the launch site at bases having the requirements specified in Section 2.6.3. As explained in Section 2.6.4, the task group would proceed to the emergency landing site with the necessary tools, spares, etc. for either the Carrier or Orbiter. Any landing of the Orbiter at other than the launch site would require the presence of the task group to prepare the vehicle for the ferry flight by installing the wing kit and additional airbreathing propulsion.



CARRIER LANDING SITES (No Cruise Required)

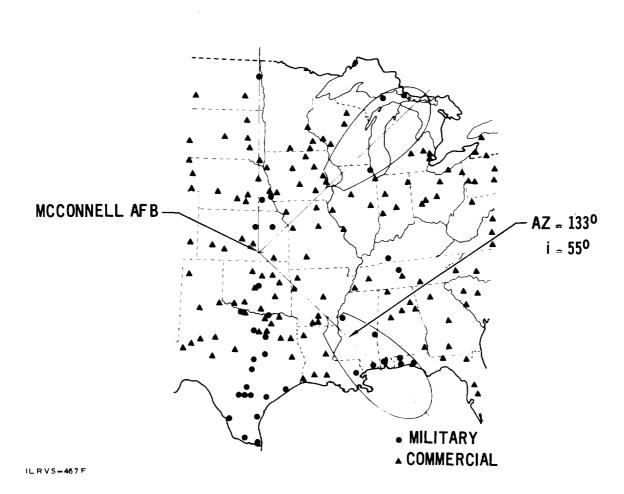


Figure 2-37

2.7 <u>Program Schedules</u> - Because of the limited number of vehicles, development and operational activities have been combined in the ILRVS Program Schedule shown in Figure 2-38.

Phase B and C schedules should be task oriented, consistent with the statement of work and should display in detail the time phased sequence of activities shown in the Task Breakdown Structure (TBS). TBS schedule orientation is important since the TBS provides the framework for defining and organizing the major elements of the program as well as identifying, in detail, the individual tasks required to accomplish the Phase B and C efforts. Activities should be defined in terms of the TBS in order that a clear relationship between the schedule and the work to be accomplished can be maintained.

Phase B Definition and Phase C Design accomplishments should be keyed to the scheduled review meetings with the NASA providing visibility of study accomplishments and the opportunity to incorporate knowledge gained from NASA in-house technology studies and interfacing programs.

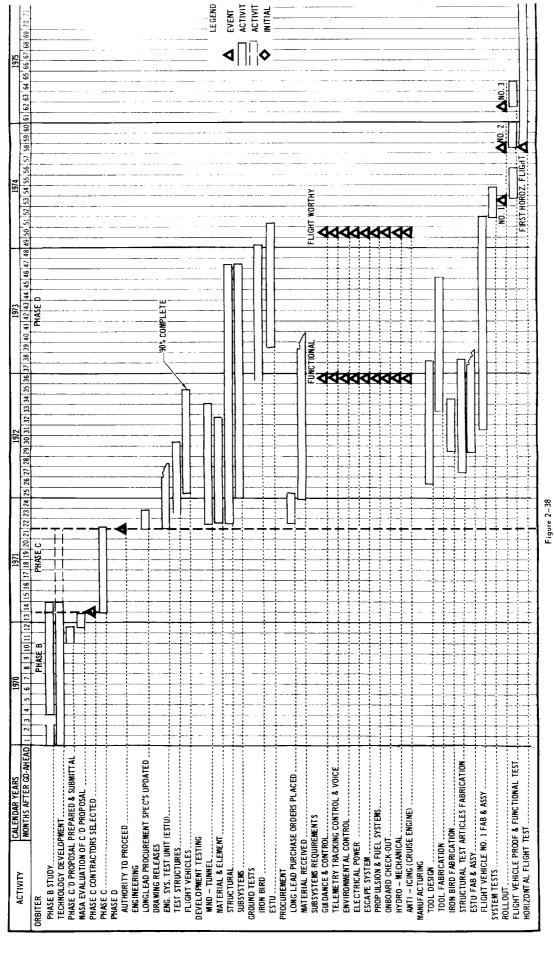
Upper level TBS schedules should be used by top management to monitor and control the project efforts. Lower level TBS schedules should be developed and monitored closely to discover at the earliest possible date any developing trends. Analysis, solutions and alternatives should be directed to the responsible management for evaluation and direction or approval. Evaluation of developing trends, favorable or unfavorable, at an early date permits the Project Manager to effectively utilize his resources and to provide management flexibility required to successfully conduct all phases of the program.

Key program milestones shown on the Program Milestone Schedule, Figure 2-39, have been selected to establish the dates that major program events must be accomplished, provide the NASA with a program overview from a management standpoint and furnish a meaningful method of evaluating progress.

The Phase D portion of the program schedule is hardware oriented and displays the functional organizations activities in sequence. Authority To Proceed (ATP) dates, as shown for Phases B, C and D are estimates. Revision of these dates will require close evaluation if the Initial Operating Capability date shown is to be maintained. Establishment of a firm technology base is also a key factor in the development of this program.

Volume III

ILRVS PROGRAM SCHEDULE



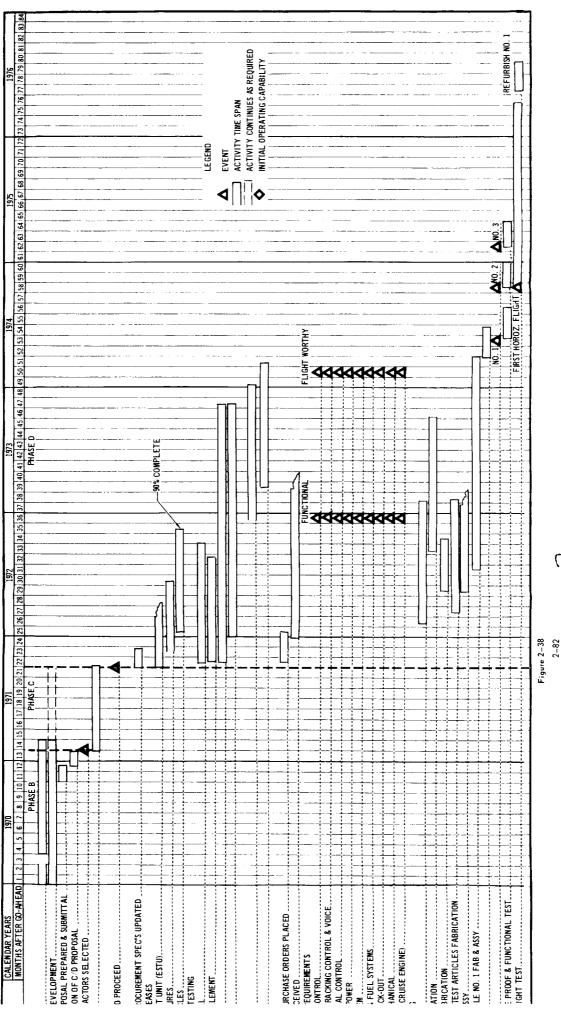
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Seentry Vehicle System || Integral Launch and

REPORT NO. MDC E0049 NOVEMBER 1969

ILRVS PROGRAM SCHEDULE



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Reentry Vehicle System integral Launch and

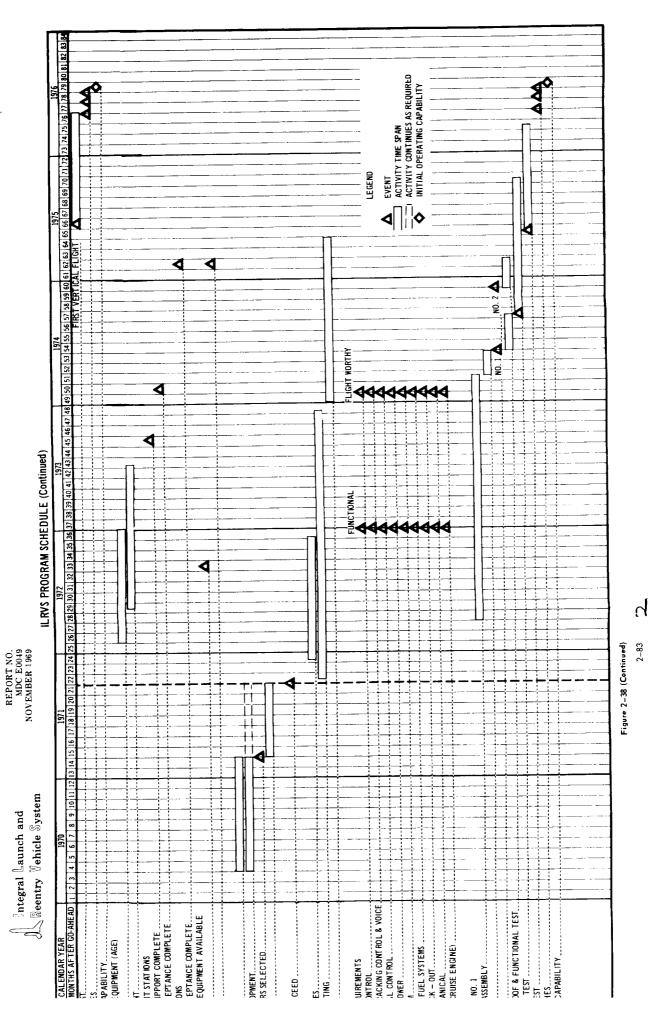
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REPORT NO. MDC E0049 NOVEMBER 1969

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TELEMETRY TRACKING CONTROL & VOICE
ENVIRONMENTAL CONTROL DEVELOPMENT TESTING PROCURE EQUIPMENT FACTORY CHECK-OUT STATIONS ANTI - ICING (CRUISE ENGINE) FLIGHT VEHICLE NO. 1
FABRICATION & ASSEMBLY GROUND HANDLING EQUIPMENT AVAILABLE FLIGHT VEHICLE PROOF & FUNCTIONAL TEST.
HORIZONTAL FLIGHT TEST SPACECRAFT ACCEPTANCE COMPLETE. LAUNCH SITE AEROSPACE GROUND EQUIPMENT (AGE) INITIAL OPERATING CAPABILITY DRAWING RELEASES. VERTICAL FLIGHT TEST ELECTRICAL POWER PROPULSION & FUEL SYSTEMS PHASE C CONTRACTORS SELECTED. GROUND TESTING SUBSYSTEMS REQUIREMENTS SYSTEM TESTS..... INITIAL OPERATING CAPABILITY PHASE B STUDY TECHNOLOGY DEVELOPMENT. ONBOARD CHECK - OUT PHASE C HYDRO - MECHANICAL AUTHORITY TO PROCEED. LAUNCH SITE STATIONS INTEGRATED LAUNCHES VERTICAL FLIGHT TEST INTEGRATED LAUNCHES ESCAPE SYSTEM DESIGN RELEASE MANUFACTURING PROCUREMENT ENGINEERING FACTORY_ ACTIVITY ROLLOUT PHASE D

Figure 2-38 (Continued)

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DONNELL DOUGLAS ASTRONAUTICS COMPANY

Integral Launch and Seentry Vehicle System

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Integral Launch and

PROGRAM MILESTONE SCHEDULE

REPORT NO. MDC E0049 NOVEMBER 1969

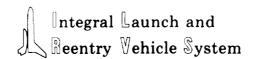
Φ 1976 4 1975 44 1974 1973 1972 1971 444 1970 4 4444 AFTER GO-AHEAD CALENDAR PLETE HEDULE COMPLETE. PLETE..... ORBITER & CARRIER. .E NO. 1 CEED RED (ORBITER) ... 90% COMPLETE ON COMPLETE. ORBITER).... RBITER) RBITER).... RBITER).. RBITER).

Figure 2–39 2–84

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Volume III



REPORT NO MDC E0049 NOVEMBER 1969

Time spans and completion dates shown on the Phase D portion of the Program Master Schedule were developed by the responsible functional organizations. Time requirements and completion dates were evaluated with interfacing functional organization requirements and program requirements. Variances were noted and resolved.

In the latter part of Phase C and early in Phase D the Work Breakdown Structure (WBS) should be finalized. At that time the Phase D Program Master Schedule will be restructured and oriented to the WBS.

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3.0 PROGRAMMATIC ANALYSIS

The programmatic implications in the design, development, and operation of the space shuttle system defined in this study are detailed in this section. Primary emphasis has been placed on the development of an operational cost model that is capable of recognizing the philosophy of airline type operations in the operation of the Carrier and the Orbiter vehicles.

This section is divided into five major subsections; Cost Methodology which outlines our background in cost analyses and the basis for the cost estimating relationship (CER's) used in estimating program costs; Programmatic Ground Rules which define the rules used in this particular analysis; Development, or Non-recurring Cost; Investment and Operational (Recurring) Cost; and Cost Effectiveness Sensitivity Analysis which presents the changes in cost to program parameters such as payload weight, probability of mission success, probability of stage recovery, turnaround time and mission duration. Conclusions necessary to the success of a space transportation system program are then summarized.

- 3.1 Cost Methodology The cost methodology used in this study has been developed from several years of advanced design studies which required progressively more sophisticated and detailed cost analysis. The data bank used to develop the cost estimating relationships (CER's) which make up the cost model are based on inhouse data and contractor study data of spacecraft, boosters and aircraft. The cost model evolved from the Optimized Cost/Performance Design Methodology (OCPDM) study, which was done for the mission analysis division of OART, and reflects the design and operational philosophy and the cost visibility of this study.
- 3.1.1 <u>Background</u> Our advanced concept cost analysis expertise has been developed over a period of time by participation in six major study contracts:
 - a) Mission Requirements of Lifting Systems (MRLS) Engineering Aspects NAS 9-3562.
 - b) Advanced Logistics System Spacecraft (ALSS) NAS 9-6081.
 - c) Multipurpose Recoverable Spacecraft (MRS) Letter of Agreement with SAMSO/Aerospace
 - d) Optimized Cost/Performance Design Methodology (OCPDM) NAS 2-5022
 - e) Logistic Spacecraft System Evolving from Gemini (Big G) NAS 9-8851
 - f) Advanced Spacecraft Subsystem Cost Analysis (ASSCA) NAS 9-9018

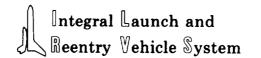
These studies expanded our understanding of the cost analysis techniques and methodology required to adequately analyze new systems and new concepts of operation. The hardware costs are strongly influenced by the spacecraft configuration, or shape, and the materials used; the sophistication of electronics, guidance and communications; and by the maintenance and design-life goals selected. Operational costs are dependent upon the launch operation philosophy; the location of recovery sites, recertification sites, and launch sites; the extent of maintenance activity during recertification and the amount of sustaining engineering, integration and management required.

The MRLS study considered a range of configurations from ballistic to lifting body shapes and included a variable geometry concept. The ALSS study considered only ballistic shapes with in-depth study of materials, subsystems and recertification. The MRS study considered several lifting body shapes in various operational modes and emphasized recertification and reuse. The OCPDM study designed a large computerized model, combining several smaller existing models and developing a cost model sensitive to small differences in structure, materials and other major subsystems. The Gemini derivative study considered the trade between existing and advanced technology system components, the advantages of on-board checkout, and the realistic costs of launch operations for an operational program. The ASSCA study is focused on two major subsystems, thermo-structure, and environmental control, for which detailed CER's are being derived.

These contracted efforts plus in-house support of advanced design studies form the background of the study methodology. In-depth analyses of the major cost categories has been accomplished in order to identify the areas where substantial reduction in cost can be expected to occur.

3.1.2 <u>Cost Estimating Models</u> - There are three cost estimating models used in this cost analysis, one for the development and hardware costs, one for the operational costs and one for the recertification or scheduled maintenance. The first is the largest and most complex.

The spacecraft development and hardware cost model is sensitive to the size and configuration, type of construction and materials, number of windows or other access openings, the type of propulsion systems and the propellants, the sophistication of the subsystems, the type of development program and the testing philosophy. This cost model is parametric in that it can be used to estimate the costs



of any spacecraft or hypersonic aircraft without regard to specific configurations through the use of size and shape factors.

The Cost Estimating Relationships (CER's) that make up this cost model are based on cost data from Mercury, Gemini, Saturn S-IVB Stage, F-4 Phantom II Fighter Aircraft, ASSET, BGRV, and industry published cost models. The CER's are mathematical relationships that utilize vehicle design and definition parameters along with program definition parameters that have been correlated with cost. The cost model is not applicable to contract pricing since it does not use detailed estimating procedures. However, the cost prediction accuracy of the model is such that it is considered adequate for use in evaluating advanced design concepts.

The cost model developed by MDAC-ED for the recently completed Optimized Cost Performance Design Methodology (OCPDM) Study was used as the basis for estimating the cost of the ILRVS vehicles. See Appendix A for a listing of the CER's and Appendix B for the CER symbol definitions. The OCPDM study MDAC Report G975 provides a complete discussion of the derivation of the CER's and the data utilized.

As stated previoulsy the OCPDM cost model was used as the basis for preparing the cost estimates with additions, modifications, and delections as necessary to estimate the ILRVS vehicles. Some of the CER's were directly applicable and some required slight adjustments. Subsystems for which there were no CER's were calculated separately. The mission module CER's were not used since the ILRVS does not have an expendable mission module. Some of the CER results that were adjusted and basic rational for these adjustments is outlined below.

- A. Subsystem design and development.
 - 1. Structural testing cost was reduced by 1/3 because of a reduction in ground test hardware quantity.
 - 2. Reaction Control System was a separate estimate since no CER was available for a gaseous $0_2/\mathrm{H}_2$ system.
 - 3. Airbreather propulsion cost is based on Rand Report RM-4670-PR November 1965.
 - 4. Orbit Maneuver System was a separate estimate since no CER was available for this subsystem.
 - 5. ECS cost was increased to provide additional equipment cost for the functions not provided by the Gemini system from which the CER was derived.

- B. AGE and Special Test Equipment cost was reduced to reflect the vast amount of on-board checkout equipment.
- C. Horizontal and vertical flight test costs were a separate calculation.
- D. Refurbishment of the RDT&E vehicles was a separate calculation.
- E. Trainers and Simulators, Mockups, and System Engineering costs in the model are calculated as a percentage of other cost items.

 Since these cost items are considerably higher than the base from which the percentage factors were derived, the cost model output of these 3 functions were reduced slightly to reflect a more realistic value.

The operational costs are estimated by relations derived from existing data which has been thoroughly analyzed in prevous work. The major effort in this area was directed toward developing factors which represent the operational philosophy of this study, assess the cost impact of these differences, and determine the adjustment factor which best represents this cost impact.

An extensive scheduled maintenance or recertification analysis is discussed in Volume II, Section 4.1 of this report. The costs presented are based upon this analysis and include both labor and material costs. Past spacecraft studies indicated that material costs form the majority of the cost of scheduled maintenance, just as they do in current aircraft practice. This directed our attention to longer subsystem life, longer time between scheduled replacement, and larger margins of safety or peak capacity. This approach led to the results presented in Section 3.3.3.

3.2 Programmatic Ground Rules - The programmatic considerations used in this study are divided into two areas; those that effect the total program cost and those that are peculiar to the development or nonrecurring phase of the program. For the most part these considerations are taken from the Program Study Outline (PSO). Other parameters such as mission reliability and launch-to-launch reliability were derived during the course of this study. Those considerations affecting the total program are given in Table 3-1. The variables shown such as launch rates were deemed significant in studying program requirements and hence, the program cost and the cost effectiveness.

The considerations applicable to the development, or nonrecurring costs which are not variables are as follows:

o A 10 percent fee was added as a separate element

rable 3-1

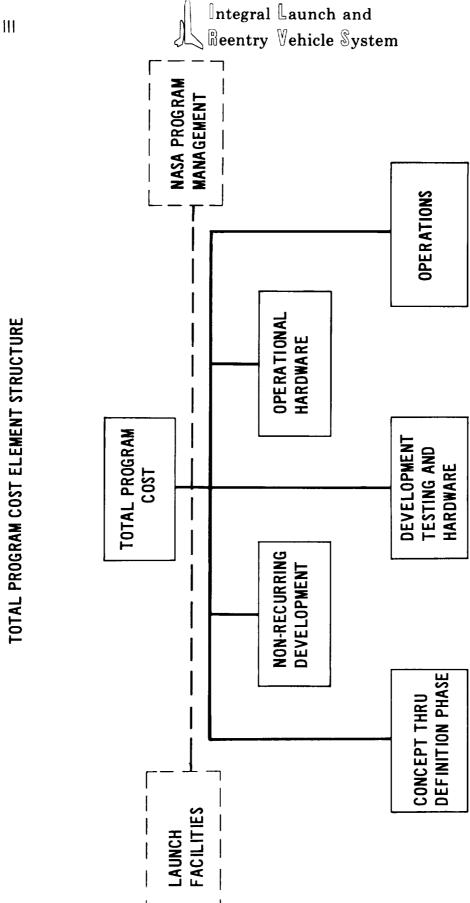
PROGRAMMATIC CONSIDERATIONS

| Reference Program | Alternate program |
|--|---|
| 1969 Dollars | None |
| Launch, landing and recertification site at same location | None |
| Payload costs not included | None |
| 10 year program | None |
| Launch rate - 12 per year | 4, 8, 10, 30, 50, 100 launches/year |
| Design life - 100 launches | Variable 20 to 200 |
| Payload to Orbit Delivery Probability = $.97$ | None |
| Payload to Orbit = 25,000 pounds | 10,000 and 50,000 pounds |
| Carrier Mission Length = 1 day Initial Turnaround time = 14 days(1) Launch to Launch Reliability = ,995 | None Variable up to 180 days Variable •95 to 1.0 |
| Orbiter Mission Length - 7 days Initial Turnaround Time = 14 days(1) Launch to Launch Reliability = .990 | 30 days Variable up to 180 days Variable .95 to 1.0 |

(1) 90% Unit Learning Applied to Turnaround Activities

- o Ground test hardware consists of 1.2 equivalent cost units (i.e., 1.2 times first unit cost)
- o Flight test hardware includes 2 complete production hardware vehicles (See Note)
- o Horizontal flight test program consists of 140 flights on the Orbiter and 118 flights on the Carrier
- o The vertical flight test program consists of 6 flights on the Orbiter, 5 flights on the Carrier and 3 combined flights
- o Three sets of AGE are included
- o Development costs reflect commonality of subsystems with the primary development cost charged to the Orbiter and a small additional cost charged to the Carrier for modifications and peculiarities
- o The airbreathing jet engines are considered off-the-shelf with 25 percent of the estimated original development cost charged for modifications.
 - NOTE: The development test program cost was based on two complete vehicles. However, since the required Orbiter inventory for the reference case (12 launches per year) is three orbiters, the third Orbiter is made available for the flight test program. The cost of this vehicle, however, is charged to investment rather than flight test. All higher launch-rate programs where the Orbiter inventory is three or greater are handled in the same manner.
- 3.3 <u>Total Program Cost</u> The cost model and the CER's are designed to generate total program costs by program phase which includes the development phase, investment phase and operational phase. The cost elements of each phase are cataloged by the cost element structure which provides the bookkeeping format for identifying and tracking the various costs associated with the systems development, investment, and operations. The total program costs were developed under the cost element structure shown in Figure 3-1.

The costs in each phase are estimated by subsystem and cost category (i.e., engineering, tooling, production, and material, CFE, subcontract) when possible or applicable. The costs are estimated in several major elements that segregates the total project into subsystems development, subsystems support, development test program, investment hardware, and operations. The CER's have been developed in sufficient detail by subsystem, and in some cases by subsystem component, to allow for subsystem trade-off studies, and provide detail cost information.



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Figure 3-1

- 3.3.1 <u>Development Phase</u> The development phase includes the conceptual and definition phases conducted by several contractors and the design and development phase which includes all program related costs up to the establishment of an Initial Operational Capability (IOC). Each cost element is estimated by the following cost categories when applicable.
 - a) Prime Contractor Engineering Design and development, testing, vendor liaison, and integration as required for each of the subsystems, includes engineering labor only.
 - b) <u>Prime Contractor Tooling</u> Initial design and fabrication of the tooling required by the prime contractor.
 - c) <u>Material</u>, <u>CFE</u>, and <u>Subcontract</u> Design and development cost of the various subcontractors for each of the subsystems as applicable.

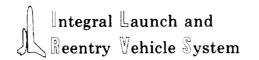
The major elements of the development phase are shown in Table 3-2 and discussed in detail in the following paragraphs.

- a) <u>Concept through Definition Phase</u> Includes preliminary design conducted by several contractors to select best concept and define preliminary specifications, schedules and plans.
- b) <u>Subsystems Design and Development</u> Includes the prime contractor and subcontractor design and development costs that can be specifically assigned to the following subsystem.
 - 1) Structure and Landing Gear Includes design and development of the basic structural items which includes primary and secondary structure, bulkheads, hatches, doors, thrust structure, fixed and movable control surfaces, internal active and/or passive cooling, external thermal protection, equipment mounting structure, and landing gear. The development cost includes the engineering design and development cost and the initial tooling design and fabrication cost for the following structural components.
 - o Entry vehicle structure
 - o Landing gear
 - 2) Power Supply Design and development of the following items:
 - o Electrical distribution system
 - o Fuel cells
 - o Batteries
 - o Reactant Supply System
 - o Ordnance

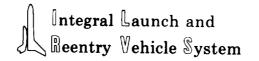
Table 3-2

TOTAL DEVELOPMENT PHASE

- A. Concept Through Definition Phase
- B. Subsystems Design and Development
 - 1. Structure and Landing Gear
 - 2. Power Supply
 - 3. Flight Controls
 - 4. Environmental Control and Life Support (ECLS)
 - 5. Avionics
 - 6. Propulsion
- C. Subsystems Support
 - 1. System Engineering
 - 2. Project Management
 - 3. AGE and Special Test Equipment
 - 4. Trainers and Simulators
 - 5. Mockups
 - 6. Ground Test Hardware
 - 7. Wind Tunnel Test
 - 8. Boost Propulsion Static Fire Test
- D. Development Test Program
 - 1. Horizontal Flight Test
 - 2. Vertical Flight Test
 - 3. Flight Test Hardware
 - 4. Spares
 - 5. Refurbishment
- E. NASA Program Management
- F. Launch and Operational Facilities



- 3) <u>Flight Controls</u> Includes the design and development cost of the hydraulics and pneumatics subsystem. Includes the power source, cylinders, accumulators, and lines, valves etc.
- 4) Environmental Control and Life Support (ECLS) Includes design and development cost of the Environmental Control System (ECS) for the crew and equipment. Also includes as a separate subsystem furnishings and equipment, which consists of food containers, first aid, survival kit and crew accessories.
- 5) <u>Avionics</u> Design and development cost of the following major subsystems:
 - o Guidance and Control
 - o Telecommunications
 - o Onboard Checkout
 - o Crew Station
- 6) <u>Propulsion Subsystems</u> The design and development cost includes the engines, non-integral tanks, and the lines, valves, and miscellaneous items for each of the following propulsion subsystems.
 - o Boost Propulsion
 - o Orbit Maneuver Propulsion
 - o Reaction Control Propulsion
 - o Turbojet Propulsion
- c) <u>Subsystems Support</u> Includes the necessary support and integration effort that cannot be identified by subsystem excepting the ground test hardware.
 - 1) System Engineering Prime contractor engineering and technical activity associated with performing mission analysis, establishing system functional requirements, performing configurational and operational analyses, and establishing design interfaces.
 - 2) <u>Project Management</u> Prime contractor cost of managing, planning, and directing the development program.
 - 3) AGE and Special Test Equipment Includes the design, development and fabrication of the AGE required to support the development phase, includes AGE for handling, transportation, component test, subsystem test, servicing, maintenance and operational equipment, launch and checkout and refurbishment equipment.
 - 4) <u>Trainers and Simulators</u> Includes the design and fabrication of the necessary training equipment, manuals and instructions.



- 5) Mockups Design and fabrication of development mockups required by the prime contractor.
- 6) Ground Test Hardware Includes all ground test hardware required by the prime contractor for the development of the system. Costs are estimated by subsystem.
- 7) Wind Tunnel Test Includes fabrication of wind tunnel models and testing for configuration development.
- 8) Boost Propulsion Static Fire Test The static test operations include all effort at the test site to plan, conduct, and analyze test results for the prime contractor's development of the boost propulsion system. Also includes the prime contractor in-plant support to the test site. This assumes that the boost engine is supplied by a subcontractor, or is GFE, and that the boost propulsion system is developed by the prime contractor.
- d) <u>Development Test Program</u> The development test program includes the development flight testing and flight test hardware required for system development and qualification.
 - 1) Horizontal Flight Testing Includes in-plant and remote site costs for the horizontal take-off and landing subsonic test program.
 - 2) Vertical Flight Testing Includes in-plant and remote site costs for the vertical take-off suborbital and orbital test program. Includes the initial buildup and site activation costs and the recurring launch costs.
 - 3) <u>Flight Test Hardware</u> Production flight hardware required to support the flight test program. Costs are estimated by subsystem.
 - 4) Spares Includes spares to support the flight test program.
 - 5) Refurbishment Includes refurbishment costs for repairs and modifications resulting from the test program to maintain and return the vehicles to an operational status.
- e) NASA Program Management Includes NASA Center cost of managing and directing the development of the system.
- f) Launch and Operational Facilities Program peculiar buildings and support installations required to support the vertical flight test portion of the development phase. These launch facilities costs are based on on-pad erection requirements.

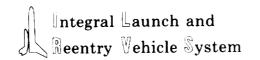


Table 3-3 presents a summary of the development phase costs for the Carrier and Orbiter vehicles. A detailed breakdown of the nonrecurring development and development testing and hardware are presented in Table 3-4.

Contractor manufacturing and test facilities costs have been excluded from the cost summaries since these costs are so dependent on the availability of facilities during contract performance.

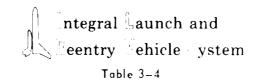
- 3.3.2 <u>Investment Phase</u> The investment phase includes the total hardware procurement cost required for the support of the operational phase. The major elements of the investment phase are given in Table 3-5 and discussed in the following paragraphs.
 - a) Additional AGE Includes labor and material required to fabricate any additional AGE, to that provided in the RDT&E development phase, that is required to support the operational phase.
 - b) Additional Facilities Any additional facilities, to those provided in the RDT&E development phase, that are required to support the operational phase.
 - c) Additional Flight Vehicles
 - o <u>Sustaining Engineering</u> Project engineering activity in support of vehicle fabrication, assembly of, and checkout.
 - o <u>Sustaining Tooling</u> All tool engineering, labor and material required to maintain the tooling during production.
 - o <u>Production</u> Manufacturing and Quality assurance labor expended by the prime contractor to fabricate, assemble, and checkout the vehicle.
 - o <u>Material</u>, <u>Contractor Furnished Equipment (CFE)</u>, and <u>Subcontract</u> Equipment and material procured by the prime contractor for the vehicle.
 - d) <u>Initial Spares</u> Includes the initial quantities of hardware components procured to support the operational phase of the program.

Table 3-6 presents a summary of the investment phase costs for the various traffic rates indicated which were derived from the programmatic ground rules given in Table 3-1.

DEVELOPMENT COST SUMMARY
Millions of 1969 Dollars

| | CARRIER | ORBITER | TOTAL |
|---|---------|---------|-------|
| CONCEPT THRU DEFINITION PHASE | 15 | 15 | 30 |
| NON-RECURRING DEVELOPMENT | 2012 | 2530 | 4542 |
| DEVELOPMENT TESTING AND HARDWARE | 757 | 503 | 1260 |
| SUBTOTAL CONTRACTOR COST | 2784 | 3048 | 5832 |
| ● NASA PROGRAM MANAGEMENT | 30 | 34 | 64 |
| LAUNCH FACILITIES | 30_ | 20 | 50 |
| SUBTOTAL | 60 | 54 | 114 |
| TOTAL DEVELOPMENT PROGRAM COST | 2844 | 3102 | 5946 |

ILRVS-369F



DEVELOPMENT COST SUMMARY Millions of 1969 Dollars

| DEVELOPMENT PROGRAM | CARRIER | ORBITER | TOTAL |
|--------------------------------|---------|---------|-------|
| Nonrecurring Cost | | | |
| Subsystems Development | | | |
| Thermal/Structure | 480 | 297 | 777 |
| Landing Gear | 22 | 10 | 32 |
| Power Supply | 17 | 37 | 54 |
| Hydraulics & Pneumatics | 81 | 6 | 24 |
| ECLS | 17 | 30 | 47 |
| Avionics | 85 | 510 | 595 |
| Propulsion | | | |
| Boost | 114 | 513 | 627 |
| Orbit Maneuver | - | 26 | 26 |
| Attitude Control | 18 | 135 | 153 |
| Airbreathing Propulsion | 133 | 76 | 209 |
| Subtotal | 904 | 1640 | 2544 |
| Subsystems Support | | | |
| System Engineering | 108 | 85 | 193 |
| Project Management | 37 | 26 | 63 |
| AGE and Special Test Equipment | 247 | 210 | 457 |
| Trainers and Simulators | 115 | 96 | 211 |
| Mockups | 23 | 14 | 37 |
| Ground Test Hardware | 303 | 180 | 483 |
| Wind Tunnel Test | 13 | 10 | 23 |
| Boost Prop. Static Fire Test | 79 | 39 | 118 |
| Subtotal | 925 | 660 | 1585 |
| Subtotal Nonrecurring Cost | 1829 | 2300 | 4129 |
| Fee @ 10% | 183 | 230 | 413 |
| Total Nonrecurring Cost | 2012 | 2530 | 4542 |

Integral Launch and Reentry Vehicle System

REPORT NO. MDC E0049 NOVEMBER 1969

Table 3-4 DEVELOPMENT COST SUMMARY (Continued) Millions of 1969 Dollars

| DEVELOPMENT TEST PROGRAM | CARRIER | ORBITER | TOTAL |
|------------------------------|---------|---------|-------|
| Development Test Program (1) | | | |
| Horizontal Flight Testing | 30 | 21 | 51 |
| Vertical Flight Testing | 77 | 87 | 164 |
| Flight Test Hardware | 440 | 255 | 695 |
| Spares | 54 | 31 | 85 |
| Refurbishment | 87 | 63 | 150 |
| Subtotal | 688 | 457 | 1145 |
| Fee @ 10% | 69 | 46 | 115 |
| | | | |
| Total Development Test | 757 | 503 | 1260 |

⁽¹⁾ See Figure 2-20, Section 2.2, For Numbers and types of flight tests.

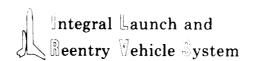


Table 3-5

INVESTMENT PHASE

- A. Additional AGE
- B. Additional Facilities
- C. Additional Flight Vehicles
 - o Sustaining Engineering
 - o Sustaining Tooling
 - o Production (1)
 - o Material, Contractor Furnished Equipment (CFE),
 and Subcontract (1)
 - (1) These two elements are segregated into the following:
 - 1. Structure and Landing Gear
 - 2. Power Supply
 - 3. Flight Controls
 - 4. Environmental Control and Life Support
 - 5. Avionics
 - 6. Propulsion
 - 7. Final Assembly and Checkout
- D. Initial Spares

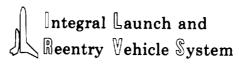


Table 3-6

INVESTMENT COST SUMMARY Millions of 1969 Dollars

| | CARRIER | ORBITER | TOTAL |
|---------------------------------|---------|---------|-------|
| 4 Flights Per Year | | | |
| Additional Flight | | | |
| Hardware Not Required | | | |
| 8 Flights Per Year | | | |
| Additional Flight | | | |
| Hardware Not Required | | | |
| 10 Flights Per Year | | | |
| Additional Flight | | | |
| Hardware Not Required | | | |
| 12 Flights Per Year | | | |
| Additional Flight Vehicles | | 94 | 94 |
| Initial Spares | | 5 | 5 |
| Project Management | | 1 | 1 |
| Fee @ 10% | | 10 | 10 |
| Total | | 110 | 110 |
| Quantity Additional Vehicles | | 1 | |
| 30 Flights Per Year | | | |
| Additional Flight Vehicles | 308 | 342 | 650 |
| Initial Spares | 17 | 18 | 35 |
| Project Management | 2 | 3 | 5 |
| Fee @ 10% | 33 | 36 | 69 |
| Total | 360 | 399 | 759 |
| Quantity of Additional Vehicles | 2 | 4 | |

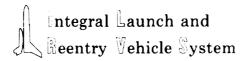


Table 3-6 INVESTMENT COST SUMMARY (Continued) Millions of 1969 Dollars

| | CARRIER | ORBITER | TOTAL |
|------------------------------|---------|---------|-------|
| 50 Flights Per Year | | | |
| Additional Flight Vehicles | 746 | 638 | 1384 |
| Initial Spares | 42 | 26 | 68 |
| Project Management | 5 | 5 | 10 |
| Fee @ 10% | 79 | 67 | 146 |
| Total | 872 | 736 | 1608 |
| Quantity Additional Vehicles | 5 | 8 | |
| 100 Flights Per Year | | | |
| Additional Flight Vehicles | 1755 | 1240 | 2995 |
| Initial Spares | 103 | 71 | 174 |
| Project Management | 11 | 8 | 19 |
| Fee @ 10% | 187 | 132 | 319 |
| Total | 2056 | 1451 | 3507 |
| Quantity Additional Vehicles | 13 | 17 | |

- 3.3.3 Operation Costs These costs are divided into three major categories: launch related costs, recertification costs, and sustaining spares costs. Launch related costs include launch operations, launch area support, mission support and training, AGE and facility maintenance, landing operations, technical support and integration. Recertification costs are divided into labor costs and replacement material costs. Sustaining spares costs are for the replenishment of the initial spares stock. These elements are discussed in the following paragraphs.
 - a) <u>Launch Operation</u> Includes all labor and material (other than recurring spares) expended at the launch site to prepare and launch a flight vehicle.
 - b) <u>Launch Area Support</u> Includes the sustaining labor and material costs of the launch site as liaison engineering and general office operations.
 - c) <u>Mission Support and Training</u> Includes cost to train replacement personnel due to attrition in order to maintain the manning levels required for aerospace and ground operations.
 - d) AGE and Facility Maintenance Includes labor and material required to maintain the launch facilities and launch site AGE in an operational readiness status.
 - e) <u>Landing Operations</u> Includes all labor and material expended at the landing site to support the vehicle.
 - f) <u>Technical Support and Integration</u> Includes prime contractor sustaining engineering plus management labor for vehicle integration at the launch site.
 - g) Recertification Includes the labor and materials required to restore a reusable entry vehicle to a flight ready condition including scheduled and unscheduled maintenance, operational spares and testing. Operational spares include all expendable components on a reusable vehicle which are replaced on a scheduled maintenance basis.
 - h) <u>Sustaining Spares</u> Replacement components for unscheduled vehicle maintenance.

As indicated in Tables 3-7, 3-8, and 3-9, launch operations account for a mininimum of 53% of the launch related costs. Included in these costs are the propellant costs which partially explains the large Carrier launch operations costs relative to the Orbiter costs. Carrier stage propellants cost about \$280,000 per flight, or for the 120 flight program about \$42.45 million. In comparison, the Orbiter propellants cost about \$64,000 per flight or about \$7.86 million for the 120 flight

Table 3-7
OPERATIONS COST

41 Launches & 40 Recoveries in 10 Years 25,000 Pound Payload Vehicle

| | Carrier | Orbiter | Total |
|---------------------------------|---------|---------|---------|
| Launch Operations | 43.26 | 13,44 | 56.70 |
| Launch Area Support | 2.91 | 11.08 | 13.99 |
| Mission Support & Training | 1.33 | 7.00 | 5.33 |
| AGE & Facility Maintenance | * 94 | 6.50 | 7.44 |
| Landing Operations | 3.73 | 3.73 | 7.46 |
| Technical Support & Integration | 6.23 | 10.02 | . 16.25 |
| Subtotal | 58.40 | 48.77 | 107.17 |
| Recertification Labor | 2.18 | 2.18 | 4.36 |
| Recertification Material | 89. | 89. | 1.36 |
| Sustaining Spares | 59.43 | 32.81 | 92.24 |
| Total | 120.69 | 84.44 | 205.13 |

Table 3-8
OPERATIONS COST

132.70 11,30 16.25 198.48 139,45 5,33 9.93 11.14 22.11 22.97 371.18 Total Orbiter 38.98 16.61 4.00 8.62 5.65 10.02 83.88 5.55 7.48 49.51 146.42 124 Launches & 120 Recoveries in 10 Years 25,000 Pound Payload Vehicle Carrier 93.72 6.36 1.33 1.31 5.65 6.23 114.60 5.59 89.94 224.76 14.63 Technical Support and Integration AGE & Facility Maintenance Mission Support & Training Recertification Material Recertification Labor Launch Area Support Landing Operations Launch Operations Subtotal Sustaining Spares Total

OPERATIONS COST

1031 Launches and 1000 Recoveries in 10 Years 25,000 Pound Payload Vehicle

| Value of the second sec | | | |
|--|---------|---------|---------|
| | Carrier | Orbiter | Total |
| Launch Operations | 534.94 | 308.29 | 843.23 |
| Launch Area Support | 27.61 | 50.78 | 78.39 |
| Mission Support & Training | 1.33 | 4.00 | 5,33 |
| AGE & Facility Maintenance | 2.25 | 13.38 | 15.63 |
| Landing Operations | 26.77 | 26.77 | 53.54 |
| Technical Support & Integration | 8.99 | 15.01 | 24.00 |
| Subtotal | 601.89 | 418.23 | 1020.12 |
| Recertification Labor | 31.68 | 31.58 | 63.26 |
| Recertification Material | 111.34 | 136.30 | 247.64 |
| Sustaining Spares | 178.19 | 98.24 | 276.43 |
| Total | 923.10 | 684.35 | 1607.45 |

program. The erection and preparation of the large Carrier stage also contributes to this cost differential as it requires a relatively greater effort to complete the pre-launch activities. All other launch related activities are more costly for the Orbiter reflecting the more complex nature of the Orbiter.

Recertification costs reflect the results of the analysis presented in Section 4.1, Volume II. The labor costs are nearly equal indicating that the larger size Carrier vehicle costs about the same as the one of greater complexity. Material costs are directly proportional to vehicle size.

3.3.4 Cost Summary and Funding Requirements — Based on the reference program of 12 launches per year and the low and high launch rates of 4 and 100 per year a contractor program cost summary is presented in Table 3-10. This table indicates the expected cost to NASA by the contractor and does not include NASA costs such as NASA program management and NASA Phase B costs. This table also indicates the average operational cost per flight for the launch rates shown and the cost per pound of payload transported for the baseline mission.

Figure 3-2 shows the funding spread assuming a Phase D go-ahead in late 1971. The total program cost is \$6293 million not including NASA costs with a peak funding in fiscal 1974 of \$1840 million. In this program the flight articles used during the test program are carried over for use in the operational program plus one additional Orbiter that is purchased under the investment phase.

Figure 3-3 shows the funding spread assuming the same Phase D go-ahead for the Orbiter as above but with the Carrier starting one year later. This moves the first Orbital flight date back eight months. An increase of \$121 million in total program cost is anticipated but the peak funding is later and lower. The peak funding of \$1720 million occurs in fiscal 1975. Again in this program, the flight test vehicles are carried over to the operational program.

- 3.4 <u>Cost Effectiveness Analysis</u> Based on the cost developed in the preceding sections and the programmatic considerations given in Table 3-1 cost effectiveness analyses were made of the spacecraft payload to orbit capability to probable annual payload requirements and the dollars per pound transport cost to orbit. Other trades include the sensitivities of program recurring costs to design life, to recertification (launch to launch) time, and to launch-to-launch reliability. The final section summarizes the significant results of these analyses.
- 3.4.1 Payload Cost to Orbit The Program Study Outline (PSO) specified that the Saturn IB/CSM (AAP Configuration) should be used as the base from which to compare the payload to orbit costs of the ILRVS systems to determine if an order of magnitude reduction in cost has been achieved. Table 3-11 presents the required comparative evaluation summary. Greater than an order of magnitude has been achieved in both cases on the same ground rules. Lofted discretionary payload costs were reduced from \$30,000 per pound to \$900 per pound and total lofted payload from \$4,000 per pound to \$92 per pound. These costs are based on Flight Test Hardware (\$440M for carriers and \$255M for Orbiters) plus \$205M for operations, and 25,000 pounds of payload per flight.

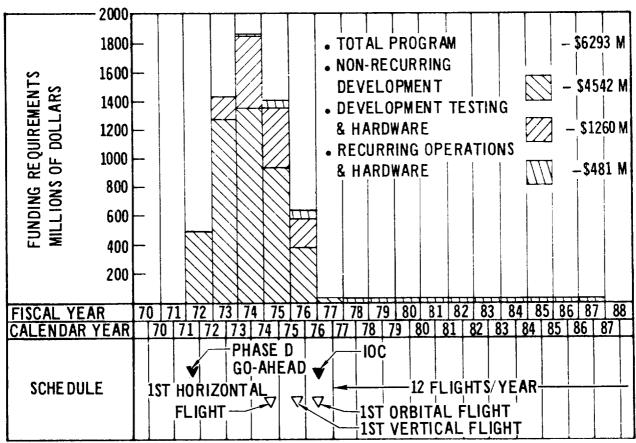


Table 3-10
CONTRACTOR PROGRAM COST SUMMARY
25,000 Pound Payload Vehicle
(Millions of 1969 Dollars)

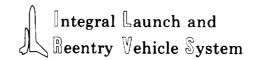
| COST RATE CATEGORY | LOW | REFERENCE | HIGH |
|---|-------------|--------------|---------------|
| | (4 FLIGHTS/ | (12 FLIGHTS/ | (100 FLIGHTS/ |
| | YEAR) | YEAR) | YEAR) |
| NON-RECURRING | 4542 | 4542 | 4542 |
| DEVELOPMENT TEST PROGRAM | 1260 | 1260 | 1260 |
| TOTAL DEVELOPMENT ADDITIONAL OPERATIONAL HARDWARE OPERATIONS COST | 5802 | 5802 | 5802 |
| | - | 110 | 3507 |
| | 205 | 371 | 1607 |
| TOTAL PROGRAM | 6007 | 6283 | 10,916 |
| AVERAGE OPERATIONAL COST/FLIGHT | 5.01 | 2.99 | 1.61 |
| AVERAGE OPERATIONAL COST/POUND OF DISCRETIONARY PAYLOAD TO ORBIT | \$201/POUND | \$119/POUND | \$64/POUND |

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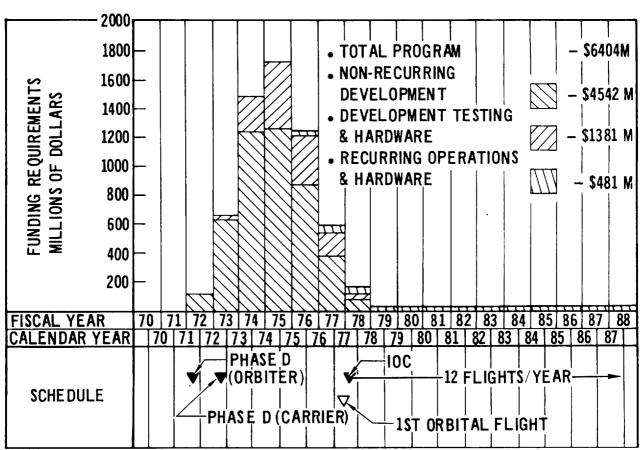
PROGRAM SCHEDULING AND FUNDING (Reference Program)



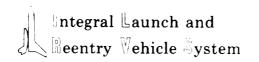
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PROGRAM SCHEDULING AND FUNDING (Stretched Program)



ILR VS-310 F



REPORT NO. MDC E0049 NOVEMBER 1969

Table 3-11 TRANSPORT COST EVALUATION

| | PROGRAM STUDY(1) OUTLINE INDEX | MDAC-ILRS(2) STUDY RESULT |
|--|--------------------------------|---------------------------|
| LOFTED DISCRETIONARY PAYLOAD | \$30,000/POUND | \$900/POUND (3) |
| TOTAL LOFTED PAYLOAD (INJECTED WEIGHT) | \$ 4,000/POUND | \$ 92/POUND |

- (1) SATURN 1B/CSM (AAP CONFIGURATION), 4 PER YEAR LAUNCH RATE
- (2) AVERAGE COST FOR 10 YEAR PROGRAM, 4 PER YEAR LAUNCH RATE, 25,000 POUND PAYLOAD VEHICLE
- (3) BASED ON FLIGHT TEST HARDWARE (2 ORBITERS AND 2 CARRIERS) PLUS OPERATIONS COST.

ILRVS-348

These reductions are primarily due to the reusability and the designed in potential of low launch-to-launch times and hence, low costs.

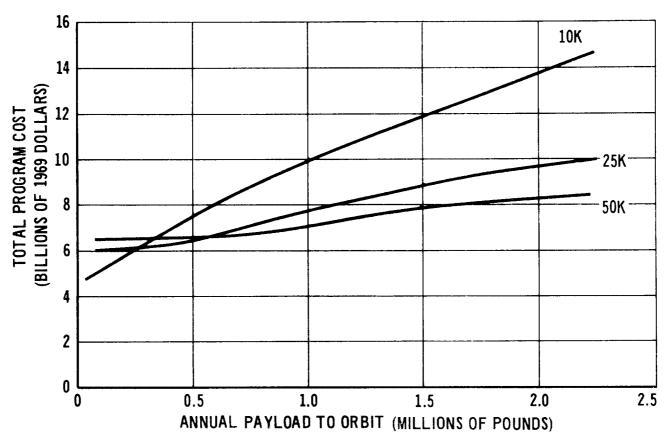
Figures 3-4 and 3-5 present the results of spacecraft payload capability against future annual payload to orbit requirements. The PSO specified three design payloads, 10,000, 25,000 and 50,000 pounds to be used in defining configuration size. Using the total program costs developed in the preceding section and a range of annual payload to orbit requirements of from 100,000 to 2.5 x 10^6 pounds the figures were developed.

Figure 3-4, effect of payload capability and annual transport demand, indicates there is a definite cost advantage to the use of larger vehicles capable of delivering 25,000 to 50,000 pounds of cargo on each flight. Below 200,000 pounds annually, there is a slight advantage to use of a smaller vehicle of 10,000 pound payload capability.

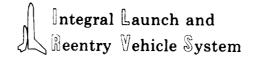
At the larger annual cargo rates, the cost of flight hardware becomes the large driving cost for small vehicles. For the 10,000 pound vehicle and a million pounds of cargo annually, the development cost and the flight hardware costs are \$5.40 and \$3.44 billion, respectively, while the operational costs are about \$940 million. At two million pounds annually, the flight hardware will cost \$6.64 billion and operations \$1.7 billion.

The larger vehicles cost slightly more to develop but reduce total costs by smaller quantities of flight hardware and lower operations costs. At two million pounds annually for the 25,000 pound vehicle, the flight hardware costs \$2.87 billion and operations \$842 million. The 50,000 pound vehicle flight hardware would cost \$1.43 billion and operations \$543 million.

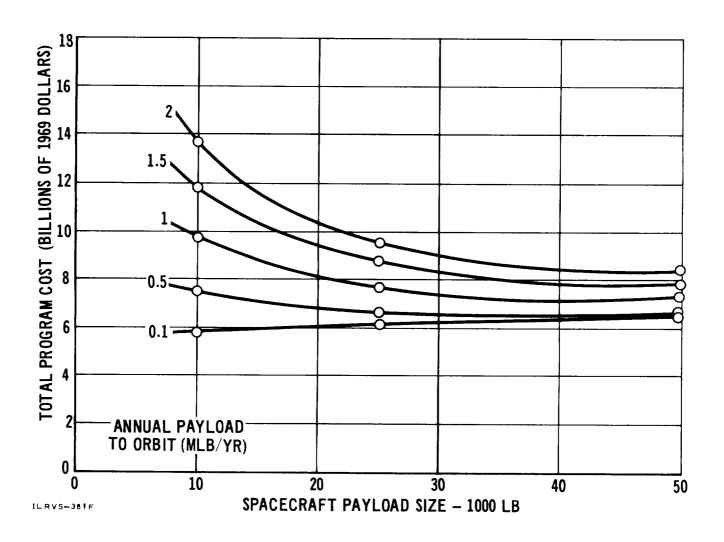
EFFECTS OF PAYLOAD CAPABILITY AND ANNUAL TRANSPORT DEMAND

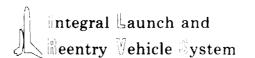


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EFFECTS OF PAYLOAD CAPABILITY AND ANNUAL TRANSPORT DEMAND 10 — Year Program





REPORT NO. MDC E0049 NOVEMBER 1969

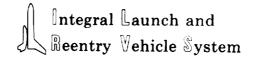
For minimum total costs, the logistics vehicle should be tailored to the cargo delivered-to-orbit requirements. As shown in Figure 3-5, when total cargo requirements are undefined, some judgements must be made concerning a desirable vehicle size. This figure indicates that designing for large payloads is desirable. For low traffic rates it will increase total costs slightly, but for high traffic will significantly reduce total costs.

At larger payloads, the curves show total program cost increases. In other words, these curves would all indicate buckets, or minimum at some specific cargo size. As indicated, the costs are rather insensitive to the specific cargo size. This again suggests that it is better to design for big cargo capability and back-off if necessary in order to hold total costs lower as the design evolves into hardware.

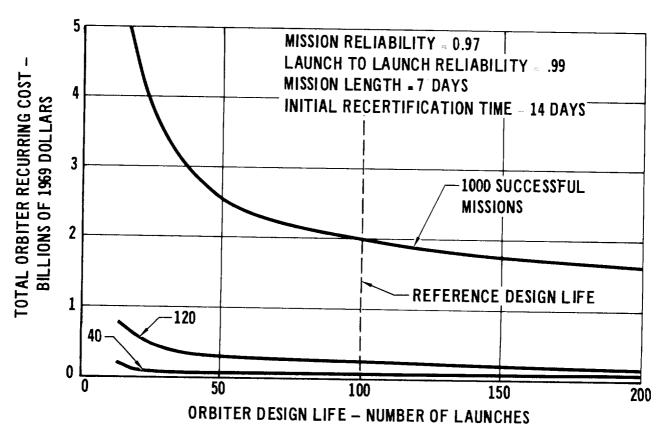
3.4.2 Program Recurring Costs/Design Life - Both the Orbiter and Carrier recurring costs have been examined with respect to design life and the results are shown in Figures 3-6 and 3-7. For both vehicles, a reference design life of 100 launches was used and the recurring costs included investment hardware, initial spares, sustaining spares, operations and recertification. The costs for vehicles used in the development program and carried over to the operational programs- two Carriers and two Orbiters were not included in the recurring cost. The cost effect on programs of 40, 120 and 1000 successful missions were examined.

Figure 3-6 indicates that as the Orbiter design life increases, the total recurring cost decreases. At low design life values, the Orbiter inventory quantities are high and the corresponding recurring costs are high. As the design life increases, the inventory quantities decrease rapidly at first and the recurring costs also decrease. The decrease in inventory and recurring cost slows as the design life becomes large. This slowdown reflects the fact that the vehicle design life is no longer a critical factor in Orbiter inventory determination. Consequently, for each program illustrated the sensitivity of recurring cost to Orbiter design life diminishes and can be disregarded after a sufficiently high design life has been achieved.

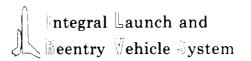
For the 40 successful mission program, a minimum inventory and recurring cost are achieved with a design life of 25 launches. For the 120 successful mission



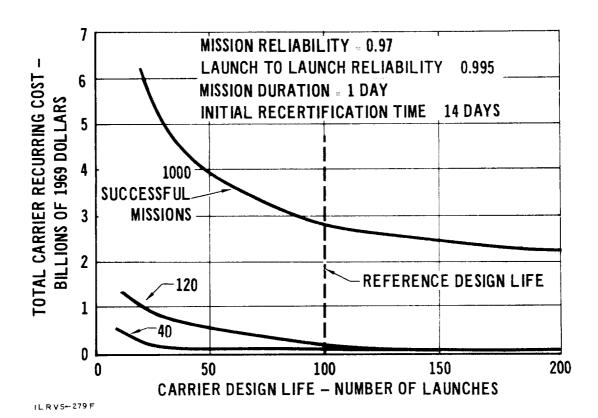
COST/DESIGN - LIFE INTERACTION (ORBITER)

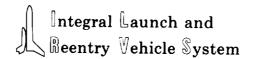


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COST/DESIGN - LIFE INTERACTION CARRIER





program, the reference design life of 100 launches represents a minimum system cost. For the 1000 successful mission program a design life of around 200 flights is appropriate.

Figure 3-7 indicates that at low design life values, the Carrier inventory quantities are very high and the corresponding recurring costs are also very high. As the design life increases, the inventory quantities decrease rapidly at first and the recurring costs also decrease. The increase in inventory and recurring cost slows as the design life becomes large. This slowdown reflects the fact that the vehicle design life is no longer a critical factor in the Carrier inventory determination. Consequently, for each program illustrated, sensitivity of recurring cost to vehicle design life diminishes and can be disregarded after a sufficiently high design life has been achieved.

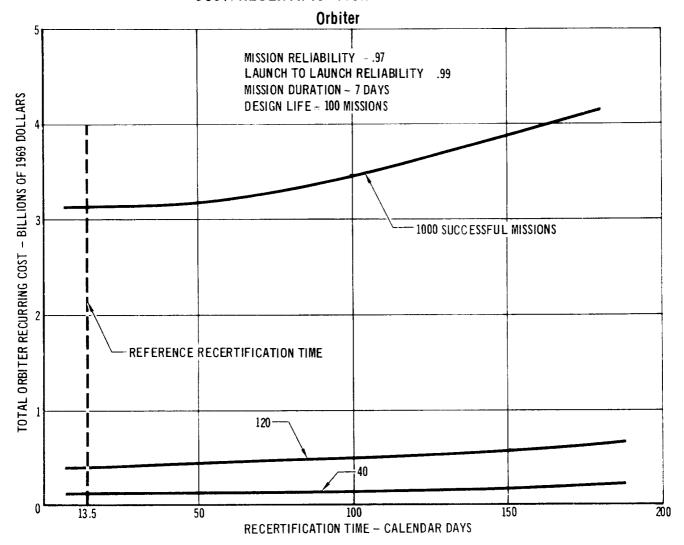
For the 40 successful mission program, a minimum inventory and recurring cost are achieved with a design life of approximately 25 launches. For the 120 successful mission program, the minimum inventory and recurring cost are achieved with a design life of around 100 launches. The reference design life of 100 launches for the 1000 successful mission program achieves a total recurring cost of 2.8 billion dollars with the recurring cost decreasing to 2.2 billion dollars if the design life is increased 100% to 200 launches.

3.4.3 Program Recurring Cost/Recertification Time - The effect of recertification time, that time from touchdown for either the Carrier or Orbiter until it is again ready for launch has been examined with respect to program recurring cost. The reference initial condition is 13.5 calendar days and an improvement rate of 90 percent is assumed. The recurring cost includes investment hardware, initial spares, sustaining spares, operations and recertification. The results are shown in Figures 3-8 and 3-9, for cost effects on programs of 40, 120 and 1000 successful missions.

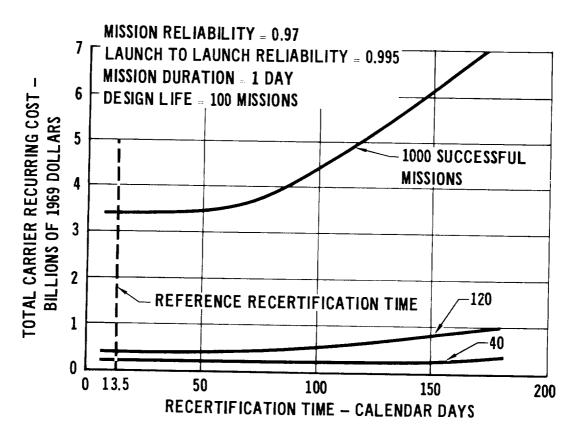
Figure 3-8 indicates that the sensitivity of the recurring costs to recertification time of the Orbiter shows two distinct phases. In the initial phase, i.e., low recertification times, the Orbiter inventory and the recurring costs associated with this hardware are not affected by an increasing recertification time. This insensitivity continues until the recertification times becomes the driving

REPORT NO. MDC E0049 NOVEMBER 1969

COST/RECERTIFICATION-TIME INTERACTION



COST/RECERTIFICATION – TIME INTERACTION CARRIER



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factor for the inventory requirements. At this recertification time the second phase begins and the recurring cost increases approximately linearly with increasing recertification time. The rate of cost increase is affected by the number of successful missions planned for the operational program.

The Orbiter recurring cost is insensitive to recertification time until the initial time approaches 25 calendar days. Since the current reference recertification time is only 13.5 days, even a doubling of the recertification time would have a minimal effect on the total Orbiter recurring cost.

Essentially the same is true for the Carrier as shown in Figure 3-9. The Carrier recurring cost is insensitive to recertification time until the initial time approaches 60 calendar days. Since the current reference time is only 13.5 days, a doubling or even tripling of the recertification time would have a minimal effect on the total Carrier recurring cost. This is due to its short mission time, one day.

3.4.4 <u>Program Recurring Cost/Reliability</u> - The interaction of launch-to-launch reliability to program recurring cost is the most significant of the factors investigated. Small changes in reliability have a sizable effect on costs as shown in Figures 3-10 and 3-11.

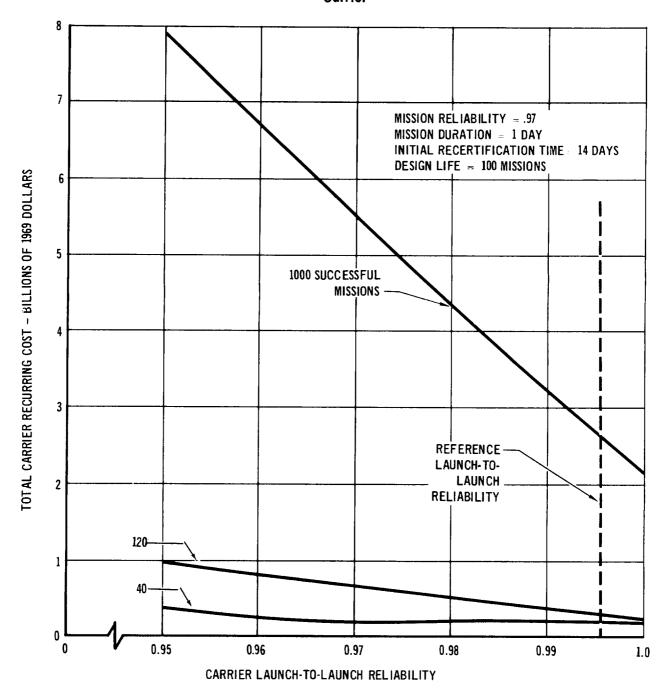
Figure 3-10 indicates the sensitivity of total Carrier recurring cost to launch-to-launch reliability. Programs of 40, 120 and 1000 successful missions for a 10 year operational phase are shown. The reference reliability is .995 and the recurring cost includes investment hardware, initial spares, sustaining spares, operations and recertification. The cost for the two RDT&E Carriers and their initial spares which are used in the operational phase are not included in the recurring cost.

Recurring costs decrease approximately linearly with increasing reliability. The rate of cost change with reliability increases as the number of successful missions increases, e.g., the recurring cost decreases 1.25 billion dollars for each .01 increase in reliability for the 1000 successful mission program while the recurring cost for the 120 successful mission program only decreases 300 million dollars for each .01 increase in reliability.

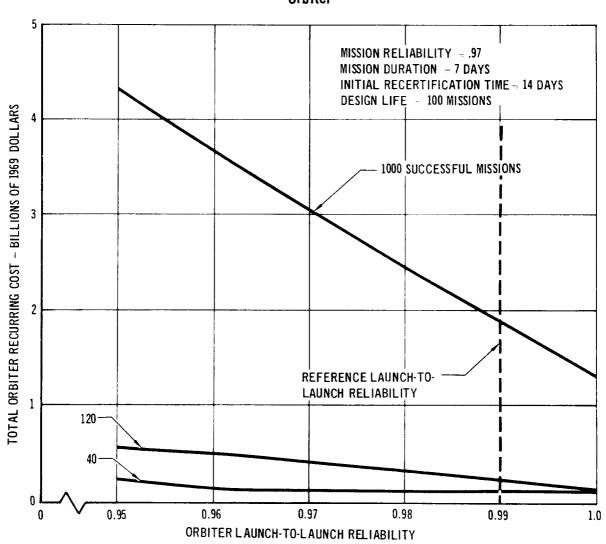
The 40 successful mission program reaches a minimum recurring cost of 200 million dollars for reliability greater than .96 because the two RDT&E Carriers can support the entire operational phase.

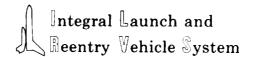


COST/RELIABILITY INTERACTION Carrier



COST/RELIABILITY INTERACTION Orbiter





The same mission parameters were investigated for the Orbiter, Figure 3-11, except with a reference reliability of .990. The results were much the same as for the Carrier.

Recurring costs increase approximately linearly with increasing reliability. The rate of cost change with reliability increases as the number of successful missions increases, e.g., the recurring cost decreases 600 million dollars for each .01 increase in reliability for the 1000 successful mission program while the recurring cost for the 120 successful mission program only decreases 60 million dollars for each .01 increase in reliability.

The 40 successful mission program reaches a minimum of 120 million dollars for reliability greater than .96 because the two RDT&E Orbiters can support the entire operational phase.

- 3.4.5 <u>Programmatic Conclusions</u> For the vehicle payloads and mission conditions examined in the preceding sections the following general conclusions can be made;
 - o Analysis confirms potential order of magnitude reduction in recurring cost
 - o The following spacecraft/annual payload to orbit combinations are the most cost-effective:

| Average annual payload | Desired spacecraft |
|-----------------------------|--------------------|
| to orbit range | payload |
| 50,000 to 200,000 pounds | 10,000 pounds |
| 200,000 to 450,000 pounds | 25,000 pounds |
| 450,000 to 2,500,000 pounds | 50,000 pounds |

- o Recertification time excursions up to 30 days have little effect on operating costs.
- o Design life specification for launch rates of less than 12 per year should be in the 25 to 100 use range; above 12 per year, in the 100 to 150 use range.
- o Launch-to-launch reliability is very critical a change of 0.01 can increase or decrease the recurring cost by 20 percent, particularly for high launch rates.

| 1 | | |
|---|--|--|

Volume III



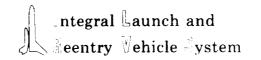
REPORT NO. MDC E0049 NOVEMBER 1969

APPENDIX A

COST ESTIMATING RELATIONSHIPS (CER)

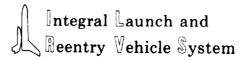
AND

CER SYMBOL DEFINITIONS



FIRST UNIT COST

| ENTRY VEHICLE AVE PROCUREMENT | PRIME CONTRACTOR LABOR | MATERIAL, CFE, AND SUBCONTRACT |
|--|--|--|
| SUSTAINING ENGINEERING (E'V) | .64 (CESRE/KENGR) ⁻⁸⁴⁸ (KENGR)23 (CESSRE) | 10 - CSEE KENGRIKMCSI |
| SUSTAINING TOOLING (E/V) | . 16 (CPE KPROD) (KTOOL) | 10 (CSTE KTOOL) (KMCS) |
| PRODUCTION, MATERIAL, CFE & SUBCONTRACT THERMAL STRUCTURE | | |
| STRUCTURE | 135 (WSCSP) ⁷⁶⁶ (KMCSP) (KACSP) [1= .05 (KMCSP)] (KPROD) | - 39501W5C5P1 ⁷⁶⁶ (KMCSP)IKACSP)[.05 KMCSP) [(KMCS |
| CREW SECTION CARGO PROPULSION SECTION | 190 (WSCPP) 766 (KMCPP) (KACPP) (KPS) 105 (KMCPP) (KPROD) | 27,33 |
| | | · (KMCS) |
| AERODYNAMIC CONTROL SURFACES | 325 (WSACSP). 766(KMACSP)(1=.05(KMACSP))(KPROD) | 3830 · WS ACSP) 766 (KMACSP) .05(KMACSP) (KMCS) |
| THERMAL PROTECTION SYSTEM | _ 322 | 720 (KMTPR) (KSR)(PSR) ^{—, 322} (SWTPR)(KMCS) |
| RADIATIVE | 203(PSR) ⁼⁻³²² (SWTPR) (KPROD) 203(PSR) ⁼⁻³²² (SWTPA) (KPROD) | 720 (KMTPA)(KSA)(PSA) - (SWTPA)(KMCS) |
| ABLATIVE | 1 | 720 (WWC) 766 (KMCS) |
| WATER COOLING | 285 (WWC) 766 (KPROD) | 720 (WWC) - (KMCS) |
| LANDING GEAR | 166 (WLG) 766 (KPROD) | 47 (WSLET) -766 (KMCS) |
| LAUNCH ESCAPE TOWER | 75 (WSLET) ^{,766} (KPROD) | 4) (#2FE(), (KWC2) |
| INFLATABLE AERODYNAMIC DEVICES | 23 (WRPC) ⁸⁴⁸ (KFROD) | 3340 (WRPC)-766 (KMCS) |
| PARACHUTE | 23 (WR SW): 848 (KPROD) | 20 10 : WRSW) 766 / KMCS/ |
| SAILWING POWER SUPPLY AND ORDNANCE | 23 (MASH) (AT ASM) | |
| ELECTRICAL DISTRIBUTION | 790 (WEPD):848 (KPROD) | 530 (WEPD) (KMCS) |
| FUEL CELL | 138 (WFC) -848 (KPROD) | 300000 (PKW) 183 (NFC) 848 (KMCS) |
| BATTERY | 34 (WB) 8 48 (KPROD) | 145 (BAT) 422 NB) 926 KMCS |
| REACTANT SUPPLY SYSTEM | 138 WRSS) - 848 (KPROD) | 107500 EKWH 1 275 KMCSI |
| HYDRAULICS & PNEUMATICS | 285 (WHPN) 766 (KPROD) | 720 (WHPN) 766 (KMCS) |
| ORDNANCE | 188 (WCRD) 848 (KPROD) | 1338 (WORD) (KMCS) |
| ECL S | | |
| ECS STORABLE GAS | 130 (WECS) 848 (KPROD) | 487400(M) 37.4(MT) 127(KECSS)(KMCS) |
| CRY OG ENIC GAS | 130 (MEC2) KERODI | 5480001M: 396 (MT)-203 (KECSCH KMCS) |
| FURNISHINGS & EQUIPMENT | 50 (WFE):848 (KPROD) | 650 WEE) (KMCS) |
| AVIONICS | , | |
| GUIDANCE & CONTROL | 146 (WGC) (848 (KPROD) | · AMGC · · KMC S) |
| TEL ECOMMUNIC ATIONS | 160 (WTC) 8 48 (K PROD) | - AMTC: :KMCSI |
| CREW STATION | 386 (WCS) -848 (KPROD) | 5000 (WCS)-766 (KMCS) |
| ON-BOARD CHECKOUT | 146 (WOBC)-848 (KPROD) | (AMOBC) (KMCS) |
| PROPULSION | 128 (WEAC) 848 (KPROD) | |
| ENTRY ATTITUDE CONTROL | 128 (WEAC) "T" (KPROD) | 3 20,000 - 240 (FECRAD) 700 INEECRA) 926 |
| ENGINES | | - £35000 - 450 (FECABL: BOO (NEECAB): 926 ' KMCS |
| TANKS | | 46000 (VTEAC) 310 (NTEAC) 848 (KMCS) |
| LINES, VALVES, & MISC. | | 59000 (WECL VM) 430 (KRED) (KMCS) |
| VERNIER MANEUVER SYSTEM | 128 (WVM) 848 (KPROD) | |
| ENGINES | 128 (17 17) | 120000 - 240(EVORA) 700 INEVORA) 926 |
| | | - 35000 - 450(FVOAB) 8001 (NEVOAB) 926 |
| | | 135000 - 450(FVDAB).800 (NEVDAB).926 - (KMCS) |
| TANKS | | 1 46000 (VTVMO) 310 (NTVMO) 848 |
| | | 46000 (VTVMD): 310 (NTVMD): 848 (1 KMCS) |
| LINES, VALVES, MISC | 4.0 | 59000 (WVMLVM)- ⁴³⁰ (KMCS) |
| MAIN ORBITAL MANEUVER | 57 (WMOM)-8 48 (KPROD) | 35000 - 450 (FMABL):800 (NEMAB):926 |
| ENGINES | | -\350000 - 475(FMRGC)-700 (NEMRGC) -926 |
| l | | = 200000 - 113 (FMRGS) 700 (NEMRGS) 926 KMCS |
| TANKS | | 3000 (VMOOX):623 (KPRMO) (NTMOO):848 |
| | | - 3000 (VMDOX) -623 (KPRMO) (NTMDO) 848 |
| | | - 3000 (VMOF) -623 (KPRMF) (NTMOF) -848 |
| | 1 | - 3000 (VMDF) ⁻⁶²³ (KPRMF) (NTMDF) ⁻⁸⁴⁸ (KMCS) |
| LINES, VALVES, MISC. | | 59000 (WMLVM): 430 (KMCS) |



FIRST UNIT COST (CONTINUED)

| ENTRY VEHICLE AVE PROCUREMENT | PRIME CONTRACTOR LABOR | MATERIAL, CFE, AND SUBCONTRACT |
|-------------------------------------|--|---|
| LAUNCH UPPER STAGE ENGINES | 30 (WLUSE) ⁻⁸⁻⁴⁸ (KPROD) | {(KPRLC) [350000 + 475 (FLRGC) · 700 }(NELRGC) · 9 26 + { 200000 + 173 (FLRGS) · 700 }(NELRGS) · 9 26 {[KMCS} |
| TANKS (INTERNAL) | [160 (WLINTS).766 + 160 (WLINTT).766] KPROD(KPT) | [99 (WLINTS).766 + 99 (WLINTT).766] [KMCS] [KPT] |
| TANKS (EXTERNAL) | 160 (WLEXT)-766 (HTEXT) -848 (KPROD) (KPT) | 99 (WLEXT) ⁻⁷⁶⁶ (NTEXT) ⁻⁸⁴⁸ (KMCS) (KPT) |
| LINES, VALVES, MISC. | | 5100 (WLLVM)-430 (KMCS) |
| LAUNCH ESCAPE SOLID ROCKET MOTORS | 118 (WLESE) ⁻⁸⁴⁸ (KPROD) | [652 (ITLEL): ³²⁸ (NMLEL): ⁹²⁶ +652 (ITLEH): ³²⁸ (NMLEH): ⁹²⁶] { KMCS] |
| DEORBIT SOLID ROCKET MOTORS | 118 (WDO) -8 48 (KPROD) | 652 (ITDO) -328 (NMDO):926 (KMCS) |
| LANDING ASSIST SOLID ROCKET MOTORS | 118 (WLA) -848 (KPROD) | 652 (ITLA) -328 (NMLA) -926 (KMCS) |
| FINAL ASSEMBLY & CHECKOUT | .0 6 (CPSE) + .96 (CPSYSE) | .40 (CPFC/KPROD) (KMCS) |
| MISSION MODULE AVE PROCUREMENT | | |
| SUSTAINING ENGINEERING (M/M) | .64 (CESRM/KENGR) ⁻⁸⁴⁸ (KENGR) + .23 (CESSRM) | . 10 (CSEM/KENGR) (KMCS) |
| SUSTAINING TOOLING (M/M) | .16 (CPM/KPROD) (KTOOL) | 1.0 (CSTM/KTOOL) (KMCS) |
| PRODUCTION, MATERIAL, CFE, & SUBC. | ,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,,, | 1 |
| STRUCTURE | | |
| SIMPLE ADAPTER | 113 (WSA) ^{.766} (KMAP) [1=.05 (KMAP)] (KPROD) | 1330 (WSA).766 (KMAP)(.05 KMAP) KMCS) |
| CARGO: PROPULSION SECTION | 190 (WSCPM).766 (KMCPMP) (KACPMP) [105 (KMCPMP)] (KPROD) | 2250(WSCPM)-766(KMCPMP)(KACPMP)(.05 KMCPMP) (KMCS) |
| POWER SUPPLY & ORDNANCE | | |
| ELECTRICAL DISTRIBUTION | 482 (WEPDM)-848 (KPROD) | 530 (WEPDM) (KMCS) |
| FUEL CELL | 76 (WFCM) 848 (KPROD) | 300000 (PKWM) 183 (NFCM) 848 (KMCS) |
| BATTERY | 19 (WBM) -848 (KPROD) | 145 (BATM) · ⁴²² (NBM) · ⁹²⁶ (KMCS) |
| REACTANT SUPPLY SYSTEM | 76 (WRSSM) . 848 (KPROD) | 107 500 (EKWHM): ²⁷⁵ (KMCS) |
| ORDNANCE | 131 (WORDM): 848 (KPROD) | 1330 (WORDM) (KMCS) |
| ECLS | , | 1330 (WORDM) (KMC3/ |
| ECS STORABLE GAS | | 487400(M): 374 (MT): 127 (KECSSM) (KMCS) |
| ECS CRYOGENIC GAS | 176 (WECSM) ⁻⁸⁻⁴⁸ (КРROD) | 548000(M)-396 (MT)-203 (KECSCM)(KMCS) |
| AVIONICS | ļ | () |
| GUIDANCE & CONTROL | 80 (WGCM)-848 (KPROD) | AMGCM (KMCS) |
| TEL ECOMMUNICATIONS | 108 (WTCM): 848 (KPROD) | AMTCM (KMCS) |
| CREW STATION | 212 (WCSM) ·848 (KPROD) | 5000 (WCSM) -766 (KMCS) |
| ON-BOARD CHECKOUT | 80 (WOB CM) ^{-8 48} (K PROD) | AMOBCM (KMCS) |
| PROPULSION VERNIER MAN EUVER SYSTEM | 76 (WVMM) ^{,8 48} (KPRO D) | |
| ENGINES | | 1[20000 - 240 (FVORAM). 700] (NEVORM). 926 +[35000 + 450 (FVOABM). 800] (NEVOAM). 926 -[20000 - 240 (FVDRAM). 700] (NEVDRM). 926 +[35000 + 450 (FVDABM). 800] (NEVDAM). 926[[KMCS] |
| TANKS | | [46000 (VTVMOM) ⁻³ 10 (NTVMOM) ⁻⁸ 48 |
| LINES, VALVES & MISC | | + 46000 (VTVMDM) ^{-3 10} (NTVMDM) ^{-8 48} (KMCS) |
| MAIN ORBITAL MAN EUVER | 848 | 59000 (WYL VMM) (KMCS) |
| ENGINES | 57 (WMOMM) ⁻⁸⁴⁸ (KPROD) | 800. 00 |
| Endines | | 3{35000 + 450 (FMABLM) ·800 (NEMABM) ·9 26 |
| | | - [350000 + 475 (FMRGCM) ⁻⁷⁰⁰](NEMRCM) ⁻⁹²⁶ + [200000 + 113(FMRGSM) ⁻⁷⁰⁰](NEMRSM) ⁻⁹²⁶ {[KMCS] |
| TANKS | | + [200000 + 113 (FMRGSM) ²⁷⁹⁰ (NEMRSM) ^{1,720} [KMCS 3000 (VMOD XM) ⁻⁶²³ (KPRMOM) (NTMODM) ⁻⁸⁴⁸ |
| | | 1 3000 (VMOO XM) ¹⁰²³ (KPRMOM) (NTMOOM) ¹⁸⁴⁸ |
| | | - 3000 (VMDOXM) (KPRMOM) (NTMDOM) (KPRMFM) (NTMOFM) -848 |
| LINES VALUES COM | | 3000 (VHDEH) 623 (KRRHEN) (NTHREN) 848) 1 KHZ |
| LINES, VALVES & MISC | 9.49 | 59000 (WMLVMM): ⁴³⁰ (KMCS) 652 (ITDOM): ³²⁸ (NMDOM): ⁹ 26 (KMCS) |
| DEORBIT SOLID ROCKET MOTORS | 65 (WDOM) ¹⁸ 48 (KPROD) | |
| LAUNCH ESCAPE SOLID ROCKET MOTORS | 65 (WLESEM) ⁻⁸⁴⁸ (KPROD) | 652 (ITLELM) ⁻³²⁸ (NMLELM) ⁻⁹²⁶ (KMCS) |
| FINAL ASSEMBLY & CHECKOUT | .06 (CPSM) + .96 (CPSYSM) | .40 (CPFCM KPROD) (KMCS) |

RESEARCH, DEVELOPMENT, TEST AND EVALUATION PHASE

| | ENCINEERING LABOR | TOOLING LABOR | MATERIAL, CFE, & SUBCONTRACT |
|--|--|---|---|
| SPACECRAFT IS C) S.C. PROJECT MANAGEMENT S. ADMINISTRATION ENTRY VEHICLE DESIGN B. DEVELOPMENT | .06 (CRE) | | 1.00 (.06 CRE 'KENGR)(KMCS) |
| THERMAL STRUCTURE CREW SECTION :TOOLING) CREW SECTION :DESIGN) CREWSECTION :TEST) | 3510 (WSCSET) ⁴⁸⁵ (KACSE) (KCCS)!KDCS)!KENGR) 1040 (WSCSET) ⁷⁸⁶ (KENGR) | 880/WSCSET; ⁷⁶⁶ (KACST)(KCT)/KT00L) | 10 (CTRCSE KTOOL)(KMCS) |
| CARGO PROPULSION SECTION (TOOLING) | 9 9 9 | 700IWSCPET): 766 (KACPT)(KCT)(KTOOL) | 1.0 (CTRCPE KTOOL)(KMCS) |
| CARGO PROPULSION SECTION (DESIGN) CARGO PROPULSION SECTION (TEST) | 3510 (WSCPET) ****(KACPE)!KCCP)!K DCP)!KENGR) 830(WSCPET) *****(KENGR) | | |
| THERMAL PROTECTION - ABLATIVE | 15750 (SWTPA; -485 (PSA)=-234(KENGR) | 3800 (SWTPA) ⁷⁶⁶ (PSA) ^{= 234} (KSA)(KTOOL) | 1.0 (CTRTPE KTOOL)(KMCS) |
| LANDING GEAR | 440 (WLG) 766 (KENGR) | 230 (WLG) 766 (KTOOL) | 1.0 (CTRLG KTOOL)(KMCS) |
| LAUNCH ESCAPE TOWER (TOOLING) | | 30 (WSLET) ⁷⁶⁶ (KTOOL) | 10 CTRLT KTOOL)(KMCS) |
| LAUNCH ESCAPE TOWER (DESIGN) LAUNCH ESCAPE TOWER (TEST) | 535 (WSLET) ⁻⁴⁸⁵ (KENGR) 130 (WSLET) ⁷⁶⁶ (KENCR) | | |
| INFLATABLE AERODYNAMIC FEVICES | | | |
| PARACHUTE | 42 (CMPCE/KMCS) ⁻⁴⁸⁵ (KENGR) | | 14330 (WCDPC)-766 (KMCS) |
| SAILWING | 42 (CMSWE KMCS)'485(KENGR) | | 21500 (WCDSW).766 (KMCS) |
| POWER SUPPLY & ORDNANCE | 766 M F W D D) 766 M F W C D) | | OUT NAME OF THE OUT OUT OF THE OUT |
| FUEL CELL | 17 (CMFCE KMCS) 485(KENGR) | | 3800000/PKW): 379 (NFC): 263,KMCS) |
| BATTERY | 320(WB) 485 (KENGR) | | 44000(BAT) 120(KMCS) |
| REACTANT SUPPLY SYSTEM | 17(CMRSSE KMCS) 485 (KENGR) | | 1260000 (EKWH) 275 (KMCS) |
| HYDRAULICS & PNEUMATICS | 1600 (WHPN) 766 (KENGR) | 320 (WHPN) 766 (KTOOL) | 7650(WHPN) ⁷⁶⁶ (KHCS) |
| ORDNANCE | 2950(WORD) 766(KENGR) | | 33670: WORD1(KMCS) |
| ECLS | | | |
| ECS | 77(CMECSE 'KMCS) 485 KENGR) | | 61549000M, 485 MT, 263 KMCS/(8 KECSS KECSC) |
| FURNISHINGS & EQUIPMENT | 3700WFE) 485 (KENGR) | | 300000.WFE: ²⁵³ ,KMCS. |
| AVIONICS GUIDANCE & CONTROL | S2 (CMGCE KMCS) 48 5 (KENCR) | | (BMCC):KMCS. |
| TELECOMMUNICATIONS | (62(CMTCE KMCS) 485 . 3160 (WDEV) 485 KENGR | | (BMTC)(KMCS) |
| CREW STATION | 2430 (WCS) 766 (KENGR) | | 35300 : WCS) 766 : KMCS) |
| ONBOARD CHECKOUT | 52 (CMOBCE KMCS) 485 (KENGR) | | (BMOBC)(KMCS) |
| PROPULSION ENTRY ATTITUDE CONTROL SYSTEM | 21 (CMEACE KMCS) 485 (KENGR) | | ŗ |
| EZCINES | | | LREECR 5000000 48600 FECRAD 478 |
| TAKKS | | | 1750000 (VTEAC) 13 (KMCS) |
| LINES VALVES MISC | | | 1265000 IMEAC) *** (KMCS) |

RESEARCH, DEVELOPMENT, TEST AND EVALUATION PHASE (Continued)

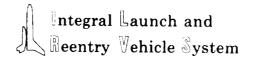
| 15.50 Pp. 7 & ORDNANCE | | ENGINEERING LABOR | TOOLING LABOR | MATERIAL, CFE, & SUBCONTRACT |
|--|----------------------------------|--|---------------|--|
| 1 CAPTER 1917 1918 1 | POWER SUPPLY & ORDNANCE | | | |
| FECTEL 17 CAPTER 17 | ELECTRICAL DISTRIBUTION | 1850 (WEPDM). 766 (KENGR) | | 2380 (WEPDM)(KMCS) |
| 17. CAM S AN THE RES | FUEL CELL | 17 (CMFCM KMCS) 485 (KENGR) | | 3800000 (PKWM)-379 (NFCM)-263 (KMCS) |
| 17 CAMPANCE 17 CAMPAN 18 CAMPANCE | BATTERIES | 320 (WBM) 485 (KENGR) | | 44000 (BATM) 120 (KMCS) |
| 13.0 (VORDIN) | REACTANT SUPPLY SYSTEM | 17 (CMRSSM KMCS)" 485 (KENGR) | | 1260000 (EKWHM) ⁻²⁷⁵ (KMCS) |
| 10 10 10 10 10 10 10 10 | ORDNANCE | 1740 (WORDM). 766 (KENGR) | | 33670 (WORDM)(KMCS) |
| \$2 (CWECSW KWCS) 485 (KENGR) WINNICATIONS 12 CACCH KWCS) 485 (KENGR) 13 CACCH KWCS) 485 (KENGR) 14 CACCH KWCS) 485 (KENGR) 15 CACCH KWCS) 485 (KENGR) 16 CACCH WATCS) 485 (KENGR) 17 CACCH KWCS) 485 (KENGR) 17 CACCH KWCS) 485 (KENGR) 17 CACCH KWCS) 485 (KENGR) | נכרז | | | |
| E & CONTROL 1 2.2 CAGCA KACS) - 485 (KENGR) 1 10.0 (WCSM) - 780 (KENGR) 1 10.0 (WCSM) - 780 (KENGR) 1 10.0 (WCSM) - 780 (KENGR) 1 10.0 (WCSM) - 880 (KENGR) 2 1 (CAWAM KACS) - 485 (KENGR) 1 1.2 MANEUVER SYSTEM 2 1 (CAWAM KACS) - 485 (KENGR) 2 2 1 (CAWAMM KACS) - 485 (KENGR) 2 3 2 1 (CAMADMM KACS) - 485 (KENGR) 3 5 VALVES, MISC 5 5 VALVES, MISC 1 7 (CAMSRM KACS) - 485 (KENGR) 1 7 (CAMSRM KACS) - 485 (KENGR) | FCS | S2 (CMECSM KMCS)-485 (KENGR) | | 6154000 (M):485 (MT):263 (KMCS) (.8 KECSSM - KECSCM) |
| E & CONTROL 57 (CMCCM KMC 5) 485 (KENCR) 100 (WDMM) 483 (KENCR) 100 (WDMM KMC 5) 485 (KENCR) 100 (WDMM KMC 5) 485 (KENCR) 100 (WDMM KMC 5) 483 (KENCR) 100 (| AVIONICS | | | |
| 62CMTCM KMCS) 485 KENGR 1300 WCSM 76M KMCS) 485 KENGR 1300 WCSM 76M KMCS 485 KENGR 1310 WCSM 76M CM CM 68 KENGR 1310 WCSM 76M CM CM 68 KENGR 1311 WANEUVER SYSTEM | GUIDANCE & CONTROL | 52 (CMGCM KMCS)'485 (KENGR) | | BMGCM (KMCS) |
| 1340 1340 1340 146 1340 146 1340 146 1340 146 1340 146 1340 146 1340 146 1340 146 1340 146 1340 146 1340 146 1340 146 1340 146 1340 1 | TEL ECOMMUNICATIONS | 62 CMTCM KMCS) 485 . 1140 (WDMM) 485 (KENGR) | | BMTCM (KMCS) |
| 15. VALVES, MISC 5. VALVES, MISC 6. CAMDAM KMCS), 483 (KENGR) | CREW STATION | 1340 (WCSM)-766 (KENGR) | | 35300 (WCSM). 766 (KMCS) |
| 1ES 1. CAVMM KMCS) ^{1,485} (KENGR) 2. VALVES MISC 2. VALVES MISC 2. (CAMOMM KMCS) ^{1,485} (KENGR) 1. CAMOMM KMCS) ^{1,485} (KENGR) 3. VALVES MISC 3. VALVES MISC 1. (CAMOMM KMCS) ^{1,485} (KENGR) 1. SOLID ROCKET MOTORS 1.7 (CADSSM KMCS) ^{1,485} (KENGR) | ON-BOARD CHECKOUT | 52 (CMOBCM KMCS) 485 (KENGR) | | BMOBCM (KMCS) |
| 21 (CMVMM KMC S) 485 (KENGR) 21 (CMMOMM KMC S) 485 (KENGR) 17 (CMDSRM KMC S) 485 (KENGR) KETMOTORS 17 (CMLESM KMC S) 485 (KENGR) | PROPULSION | | | |
| OTO RS 17 (CMDSRM KMCS) 485 (KENGR) 17 (CMDSRM KMCS) 485 (KENGR) | VERNIER MANEUVER SYSTEM | 21 (CMVMM KMCS)-485 (KENGR) | | |
| OTORS 17 (CMDSRM KMCS) 485 (KENGR) 17 (CMDSRM KMCS) 485 (KENGR) | ENGINES | | | {(LEVORM) { 5000000 + 48600 (FVOR AM)-678 |
| OTORS 17 (CMDSRM KMCS) 485 (KENGR) 17 (CMDSRM KMCS) 485 (KENGR) | | | | . (LEVOAM) 10000000 . 84000 (FVOABM) .678 |
| OTORS 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) | | | | . (LEVDRM) [5000000 + 48600 (FVDR AM) -678 |
| | | | | (LEVDAM) 10000000 - 84000 (FVDABM) 678 KMCS |
| OTORS 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) | TANKS | | | 61 |
| OTORS 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) | | | | 17 50000 (VTVMOM) (VTVMOM KMCS |
| OTORS 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) 17 (CMLESM KMCS) ⁻⁴⁸⁵ (KENGR) | LINES, VALVES, MISC | | | 1265000 (WVMM) 410 (KMCS) |
| 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (K ENGR) 17 (CML ESM KMCS) ⁻⁴⁸⁵ (K ENGR) | MAIN ORBITAL MANEUVER | 21 (CMMOMM KMCS)'485 (KENGR) | | |
| 17 (CMDSRM KMCS) 485 (KENGR) 17 (CMLESM KMCS) 485 (KENGR) | ENGINES | | | } (LREMAM) 10000000 . 84000 (FMABLM)-678 |
| 17 (CMDSRM KMCS) ⁴⁸⁵ (KENGR) 17 (CMLESM KMCS) ⁴⁸⁵ (KENGR) | | | | · (LREMCM) 50000000 · 1405000 (FMRGCM)-423 |
| 17 (CMDSRM KMCS) 485 (K ENGR) 17 (CMLESM KMCS) 485 (K ENGR) | | | | . (L REMSM) 50000000 - 865000 (FMRGSM) ⁻⁴²²] (KMCS |
| 17 (CMDSRM KMCS) 485 (K ENGR) 17 (CMDSRM KMCS) 485 (K ENGR) | TARKS | | | |
| 17 (CMDSRM KMCS) 485 (K ENGR) 19 (CMLESM KMCS) 485 (K ENGR) | | | | |
| 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) A070RS 17 (CMLESM KMCS) ⁻⁴⁸⁵ (KENGR) | | | | 9600 (VMOOXM) - (VMDOXM) 00089 |
| 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (K ENGR) A070RS 17 (CMLESM KMCS) ⁻⁴⁸⁵ (K ENGR) | | | | . (VMOFM) 600 . (VMDFM)-600 [KMCS] |
| 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) 17 (CMLESM KMCS) ⁻⁴⁸⁵ (KENGR) | | | | |
| 17 (CMDSRM KMCS) 485 (KENGR) A O T O RS | LINES, VALVES, MISC | | | 1265000 (WMOMM) -410 (KMCS) |
| 17 (CALESM KMCS) 485 (KENGR) | DEORBIT SOLID ROCKET MOTORS | 17 (CMDSRM KMCS) ⁻⁴⁸⁵ (KENGR) | | 39 0000 (ITDOM) 193 (KMCS) |
| | LAUNCH ESCAPE SOLID ROCKETMOTORS | 17 (CMLESM KMCS). 485 (KENGR) | | 39 0000 (ITLELM) 193 (KMCS) |

| ATION PHASE (Continued) | |
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| | ENGINEERING LABOR | TOOLING LABOR | MATERIAL, CFE, & SUBCONTRACT |
|---|--|--|---|
| VERNIER MANEUVER SYSTEM ENGINES | 21 (CMVME/KMCS) ⁴⁸⁵ (KENGR) | | {LREVORX (5000000 + 48600 (FVORA) ⁻⁶⁷⁸ + (LREVOA) [†] 100000000 + 84000 (FVOAB) ⁻⁶⁷⁸ |
| TANKS | | | + (LREVBR) 5900000 + 48600 (FVDRA)·0/8 + (LREVBA) 10000000 + 84000 (FVDAB) ⁶⁷⁸ |
| LINES, VALVES, MISC MAIN ORBITAL MANEUVER SYSTEM | 2) (CMMOME KMCS) 485 (KENGR) | | 1265000 (WVM) ⁻⁴¹⁰ (KMCS) |
| ENGINES | | | (LREMA) 10000000 - 84000 (FMABL) ⁻⁶⁷⁸ - (LREMC) 50000000 - 1405000 (FMRGC) ⁴²² - (LREMS) 5000000 - 865000 (FMRGS) ⁴²² KmCS [†] |
| | | | 96000 (VMOOX1 -500 , (VMDOX1 -600) . (VMDOX1 -600 |
| LINES, VALVES, & MISC | | | 1265000 (WMDM) ^{,410} (KMCS) |
| LAUNCH UPPER STAGE ENGINES | 11600 (WLUSE) ^{, 570} (KENGR) | | |
| TANKS (INTERNAL), TOOLING | | [610(WLINTS). 766 . (WLINTT). 766 [KTOOL] | 1.01CTRTI/KTOOLKKMCS) |
| DESIGN | {2440 {WLINTS 485 . (WLINTT) 485 KENGRI | | |
| TEST | [531][(WLINTS) 766 . (WLINTT) 766 KENGR | | |
| TANKS (EXTERNAL), TOOLING | 2.00 | 610(WLEXT). 766 (KTOOL) | I.Q (CTRTE KTOOL)/KMCS) |
| DESIGN | 2440 (WLEXT) (X ENGR) 531 (WLEXT) (KENGR) | | |
| LINES, VALVES, & MISC | Š | | SO (CELUSE/KENGR) (KMCS) |
| LAUNCH ESCAPE SOLID ROCK ET MOTOR | 17(CMLESE KMCS) ⁻⁴⁸³ (KENGR) | | 390000 (ITLEL) |
| LEUNDING ASSIST SOLID ROCKET MOTOR | 17 (CMLAE KMCS) 485 (KENGR) | | 390000 (ITLA) 193 (KMCS) |
| MISSION MODULE DESIGN & DEVELOPMENT | | | |
| STRUCTURE | | 186(WSA) 766 (KTCOL) |) 0 (CTRA/KTOOL)(KMGS) |
| SIMPLE ADAPTER (DESIGN) | 760 (WSA) 485 (KENGR) | | |
| SIMPLE AD APTER (TEST) CARGO PROPULSION SECTION (TOOLING) | 187 (WSA). (DO (KENGR) | 466(WSCPM) 766 (KACPMT)(KTOOL) | 1.0 (CTRCPM/KTOOL)(KMCS) |
| CARGO PROPULSION SECTION (DESIGN) | 3050(WSCPM):485 (KACPME)(KDCPM)(KENGR) | | |
| CARGO PROPULSION SECTION (150) | 004 (Mount) (Mindel) | | |

| _ |
|----------------------------|
| (Continued) |
| PHASE (|
| TEST AND EVALUATION PHASE |
| AND EV |
| T, TEST |
| LOPMEN |
| H, DEVE |
| RESEARCH, DEVELOPMENT, TES |

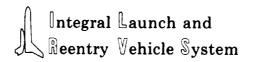
| | KENEAKUH, DEVELUPMENI, IENI AND EVALUATION FRANCE, (COMMOSE) | ION LIASE (Continued) | | |
|---|--|----------------------------------|-------------------------------------|--|
| | ENGINEERING LABOR | PRODUCTION LABOR | MATERIAL, CFE & SUBCONTRACT | |
| AGE | | | | |
| NONRECURRING HANDLING & SUPPORT | .07 (CESRE - CESRM) | | | |
| SUBSYSTEMS CHECKOUT | .35(CESSRE . CESSRM) | | . 10 (CMRSYS) | |
| RECURRING MIDDOUT | (1000) | 19040 277300 | 19040 (01) THING | |
| SUBSYSTEMS CHECKOUT | .03.03 (CESSRE - CESSRM) (QAGE 1) | BB(CPSYSE CPSYSM)(QAGEI) | .80 (CMTSYS)(QAGEI) | |
| FACILITIES RECOVERY SITE FACILITIES | LLM 16.468 (1-E25) · 2.065 (E25)(NS) | | 304(CPRFRS)(KMCS (KLRS)) | |
| | -1,33 (VLM)(1-E25) + ,205 (E25)(MS) + [11,54 (1-LLM)](| -LM)}{ | | |
| LAUNCH SITE FACILITY ACTIVATION | }3125 (KLRS){ 220 10 2 (KLRS) | | 4.0 (CPRFLA)(KMCS KLRS) | |
| LAUNCH SITE CONSTRUCTION | | | (3376) (TSC) ⁻⁴⁸⁵ (KMCS) | |
| TRAINERS | 4 (CSEE . CSEM) | .20(CTP) | 1.60 (CMTSTR + CMTSYS) | |
| SYSTEM INTEGRATION | | | | |
| SYST EM ENGINEERING | .50 (CEDD) | | .05 (.50 CEDD)/ENGR)(KMCS) | |
| SYSTEM TESTOPERATIONS AIRDROP TEST OPERATIONS | [536,400 (KLRS) - 13340000 (KMCS) (LSTOA) | | .623 (CAHTS) (KMCS) (LSTOA) | |
| SNOTT A STREET CHILDOC | | | | |
| WIND TUNNEL | 95000(KCWT)(KENGR) | | (1.75 (CRSSF/KLRS) | |
| THERMAL QUALIFICATION | 1580 (WDEV WDMM) OUU (KENGR) | | KPRL2(QFXWPLUS) | |
| STATIC FIRE (L U S.) | 267600 - 49500 (QF1_1) (NE) ⁻²⁰ (FLRGS - FLRGC) ^{**} (KLRS) | .RS) | KPRLI (FLRGS · FLRGC)(NE) KMCS | |
| | (30) | | | |
| LAUNCH OPERATIONS | (KLRS) ≥ 18590 (N) = 400 + 10094 (N) = -349 + 19373 (N) = 0.25 | 2.55 | 1182 (WLOH) + 1,2825 (WLFH) | |
| | 1906.1 | | | |
| | | 52.13 × 10 ⁵ (USP) 1; | + 8395 (WFOC) + .2310 (WSTO)] | |
| | | 14-4(BAL) | COMPANY (COMPANY) | |
| LAUNCH AREA SUPPORT COST | $\{(2,2,300),(N)^{-13}\}_{\{(2,11,1)}^{-4},(75C)^{-48}\}_{N-1}$ | | | |
| | . 30 281 36 (MBV) . 55 (1BV). 44 (MLB) 64 (1LB) 1 KLR5 | 51 | | |
| MISSION CONTROL SUPPORT | 16942 36 (MBV) + 55 (IBV) + 44 (MLB) + 64 (ILB) ((KLRS) | | | |
| AGE KAINTENANGE | QF2 (\$ 162251(N) ⁹³³ (KLRS) | | | |
| | _ Z | | | |
| FACIL, MAINT EN ANCE | (2 39218 (N) -: 83) (2,1)×10 ⁻⁴ ((TSC) ⁻⁴⁸⁵ (KLRS) N 1 | | .01 (CRFAC) | |
| | | | | |



RESEARCH, DEVELOPMENT, TEST AND EVALUATION PHASE (Continued)

| | ENGINEERING LABOR | PRODUCTION LABOR | MATERIAL, CFE, & SUBCONTRACT |
|--|---------------------------------------|---|---|
| RECOVERY OPER COST Customer Cost | (1-VLM)(188000(1.E2S) | | |
| LAUNCH SITE PECULIAR AGE | · · · · · · · · · · · · · · · · · · · | | |
| TRANSPORTATION | (8 l 405 2) ₁ | 2.4 (CRPLSA)(KMCS/KLRS) (KMCS)(QF2) { 20000 (ATS) 14000 (LTS) - 115000 (BTS)} | |
| MOCKUPS | 565 (WDEV - WDMM) -485 (KENGR) | 20 (CTP) | LAVAN CER (MARON) VALCE |
| SYSTEM TEST HARDWARE | | 81077 | 1 0(20 CTP (KPROD) (KMCS) |
| AIRDROP TEST HARDWARE , SUSTAINING ENGINEERING | (-33) (CSEE) (QA1) | | (.10) (CASE/KENGR) (KMCS) |
| SUSTAINING TOOLING | | (-10) (CAHP/KPROD) (KTOOL) | 1.0 (CAST/KTOOL) (KMCS) |
| PRODUCTION, MATL, CFE & SUBC | | 1 | |
| THERMAL/STRUCTURE | | 1 | |
| STRUCTUR E | | .7 (QA1) (CPSCS/KMCSP + 1.2 CPSAC/KMACSP) | .7 (QA1) (CMSCS/KMCSP + 1.2 CMSAC/KMACSP) |
| THERMAL PROTECTION | | .54 (QA1) (CPTPR + CPTPA) | -84 (QA1) (CM1PR/KMTPR - CMTPA/KMTPA) |
| LANDING GEAR | | (-77)(CPLG) (QA1) | (.85) (CMLG) (QA1) |
| INFLATABLE AERO DEV | | 1 | |
| PARACHUT E | | (.77) (CPP) (QA1) | (-85) (CMP) (QA1) |
| SAIL WING | | (.77) (CP5W) (QA1) | .85 (CMSW) IQA I) |
| POWER SUPPLY & ORDNANCE | | | |
| ELECTRICAL DISTRIBUTION | | 60000 (KPROD) (QA1) | 100000 (KMCS) (QA1) |
| BATTERIES | | 1200 (KPROD) (QA1) | 3200 (KMCS) (QA1) |
| HYDRAULICS & PNEUMATICS | | (-77) (CPHP) (QA1) | 85 (CMHP)(QA1) |
| ORDNANC E | | (-10) (CPO) (QA1) | (-10) (CMO) (QA1) |
| ECLS | | ! | |
| ECS | | 6000 (KPROD: (QA1) | 180000 (KMCS) (QA1) |
| FURNISHINGS & EQUIPMENT | | 2500 (KPROD) (QA1) | 50000 (KMCS) (QA1) |
| AVIONICS | | | |
| GUIDANCE & CONTROL | | 17000 (KPRODI (QA1) | 1329000 (KMC5) (QA1) |
| TELECOMMUNICATIONS CREW STATION | | 17000 (KPROD) (QA1) | 1500000 (KMCS) (QA1) |
| PROPULSION | | .77 (CPCS) (QA1) | .85 (CMCS) (QA1) |
| LANDING ASSIST | | | |
| FINAL ASSEMBLY & CHECKOUT | | (-77) (CPLA) (QA1) | .92 (CMLA) (QA1) |
| | | (-D6) (CAPTS)50 (CAPSS) | -40 (CAHFC/KPROD) (KMCS) |
| GROUND TEST MARDWARE TYPICAL EQUATION BOOSTED FLIGHT TEST (TYPICAL EQUATION) | | (FIRST UNIT SUBSYSTEM COST) (QGI) | (FIRST UNIT SUBSYSTEM COST) (QGI) |
| AVE PROCUREMENT | | (FIRST UNIT SUBSYSTEM COSTHQUAN TITY) XLC | (FIRST UNIT SUBSYSTEM COSTHQUANTITY) XLC |
| Jranes . | | 20 (AVEPROCUREMENT: | 20 (AVE PROCUREMENT) |
| | INVESTMEN | T PMASE | |
| NVESTMENT PHASE - TYPICAL EQUATIONS | | | |
| AVE PROCUREMENT | (FIRST UNIT COST) (QF) KLC | (FIRST UNIT SUBSYSTEM COST)(QF) XLC | (FIRST UNIT SUBSYSTEM COST)(QF)XLC |
| SPARES | | 10 (AVE PROCUREMENT) | 10 (AVE PROCUREMENT) |
| ADDITIONAL AGE | | | |
| HANDLING & SUPPORT | OS Oberse ceremina | | |
| SUBSYSTEMS CHECKOUT | 05 .07(CESRE - CESEM) QAGE 2 | 05 CPSE CPSH)(QAGE2) | .22(CMTSTR) (QAGE 2) |
| | 051 39/CESSRE + CESSRMHQAGE 2 | BRICPSYSE - CPSYSM) (QAGE 2) | .80(CMTSYS) (QAGE 2) |
| DOITIONAL FACILITIES | | | 250000000 (KMC S) |

Volume III



REPORT NO. MDC E0049 NOVEMBER 1969

APPENDIX B

SYMBOL DEFINITION

REPORT NO. MDC E0049 NOVEMBER 1969

APPENDIX B SYMBOL DEFINITION

<u>A</u>

AGEF Age Factor

AMGC First Unit Material, CFE, & Subcontract Cost for Guidance and

Control Subsystem - Entry Vehicle (E/V).

AMGCM First Unit Material, CFE, & Subcontract Cost for Guidance and

Control Subsystem - Mission Module (M/M).

AMOBC First Unit Material, CFE, & Subcontract Cost for Onboard Checkout

Subsystem - E/V.

AMOBCM First Unit Material, CFE, & Subcontract Cost for Onboard Checkout

Subsystem - M/M.

AMTC First Unit Material, CFE, & Subcontract Cost for Telecommunications

Subsystem - E/V.

AMTCM First Unit Material, CFE, & Subcontract Cost for Telecommunications

Subsystem - M/M.

ATS Air Transport Switch.

B

BAL Ballistic Configuration Switch.

BAT Energy in Watt-Hours per battery, E/V.

BATM Energy in Watt-Hours per battery, M/M.

BMGC Material, CFE, & Subcontract - Design & Development Cost for

Guidance & Control Subsystem - E/V.

BMGCM Material, CFE, & Subcontract - Design & Development Cost for

Guidance & Control Subsystem - M/M.

BMOBC Material, CFE, & Subcontract - Design & Development Cost for

Onboard Checkout Subsystem - E/V.

BMOBCM Material, CFE, & Subcontract - Design & Development Cost for

Onboard Checkout Subsystem - M/M.

BMTC Material, CFE, & Subcontract - Design & Development Cost for

Telecommunications Subsystem - E/V.

BMTCM Material, CFE, & Subcontract - Design & Development Cost for

Telecommunications Subsystem - M/M.

BTS Barge Transportation Switch.

<u>C</u>

CAHFC Production labor cost of airdrop hardware final assembly and checkout.

CAHP Production labor cost of airdrop hardware excluding final assembly and checkout.

CAHTS Total cost of airdrop hardware Thermal/Structural group.

CAPSS Production labor cost of airdrop hardware for non-structural

subsystems.

CAPTS Production labor cost of airdrop hardware for Thermal/Structural

group.

CASE Sustaining engineering labor cost for airdrop hardware.

CAST Sustaining tooling labor cost for airdrop hardware.

CEDD Prime Contractor Engineering E/V and M/M D&D Cost = CESRE +

CESSRE + CESRM + CESSRM.

CELUSE Prime Contractor Engineering Design and Development Cost of

Launch Upper Stages Engines.

CESRE Prime Contractor Engineering Design and Development Cost of E/V

Thermal/Structure Group and Launch Upper Stage Tanks.

CESRM Prime Contractor Engineering Design and Development Cost of M/M

Thermal/Structure Group.

CESSRE Prime Contractor Engineering D&D Cost of all non-structural

subsystems - E/V.

CESSRM Prime Contractor Engineering D&D cost of all non-structural

subsystems - M/M.

CMCS Material, CFE, and Subcontract first unit cost of the Crew

Station, E/V.

CMDSRE Material, CFE, and Subcontract Design & Development Cost of the

Deorbit Solid Rocket Motor Subsystem - E/V.

CMDSRM Material, CFE, and Subcontract Design & Development Cost of the

Deorbit Solid Rocket Motor Subsystem - M/M.

CMEACE Material, CFE, and Subcontract Design & Development Cost of the

Entry Attitude Control Subsystem - E/V.

CMECSE Material, CFE, and Subcontract Design & Development Cost of the

Environmental Control Subsystem - E/V.

CMECSM Material, CFE, and Subcontract Design & Development Cost of the

Environmental Control Subsystem - M/M.

| Volume III | Integral Launch and REPORT NO. MDC E0049 NOVEMBER 1969 |
|------------|--|
| CMFCE | Material, CFE, and Subcontract Design & Development Cost of the |
| | Fuel Cell Subsystem E/V. |
| CMFCM | Material, CFE, and Subcontract Design & Development Cost of the |
| | Fuel Cell Subsystem - M/M. |
| CMGCE | Material, CFE, and Subcontract Design & Development Cost of the |
| | Guidance Control Subsystem - E/V. |
| CMGCM | Material, CFE, and Subcontract Design & Development Cost of the |
| | Guidance and Control Subsystem - M/M. |
| CMHP | Material, CFE, and Subcontract first unit cost of the Hydraulics and |
| | Pneumatics. |
| CMLA | Material CFE, and Subcontract first unit cost of the Landing Assist |
| | Solid Rocket Motor - E/V. |
| CMLAE | Material, CFE, and Subcontract Design & Development Cost of the |
| | Landing Assist Solid Rocket Motor Subsystem - E/V. |
| CMLESE | Material, CFE, and Subcontract Design & Development cost of the |
| | Launch Escape Motors Subsystem - E/V. |
| CMLESM | Material, CFE, and Subcontract Design & Development cost of the |
| | Launch Escape Motors Subsystem - M/M. |
| CMLG | Material, CFE, and Subcontract first unit cost of the Landing Gear. |
| CMMOME | Material, CFE, and Subcontract Design & Development cost of the |
| | Main Orbital Maneuver Subsystem - E/V. |
| CMMOMM | Material, CFE, and Subcontract Design & Development Cost of the |
| | Main Orbital Maneuver Subsystem - M/M. |
| СМО | Material, CFE, and Subcontract first unit cost of the Ordnance, E/V. |

CMOBCM Material, CFE, and Subcontract Design & Development cost of the Onboard Checkout Subsystem - M/M.

CMP Material, CFE, and Subcontract first unit cost of the Parachute, E/V.

Material, CFE, and Subcontract Design & Development cost of the

CMPCE Material, CFE, and Subcontract Design & Development cost of the

Recovery Parachute Subsystem - E/V.

Onboard Checkout Subsystem - E/V.

CMRSSE Material, CFE, and Subcontract Design & Development cost of the Reactant Supply Subsystem - E/V.

CMOBCE

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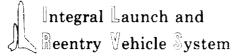
CPCS



REPORT NO. MDC E0049 NOVEMBER 1969

| Votaine III | Reentry Vehicle System NOVEMBER 1 |
|-------------|---|
| CMRSSM | Material, CFE, and Subcontract Design & Development cost of the |
| | Reactant Supply Subsystem - M/M. |
| CMSAC | Material, CFE, and Subcontract first unit cost of the Aerodynamic |
| | Control Surfaces. |
| CMSCS | Material, CFE, and Subcontract first unit cost of Crew Section |
| | Structure. |
| CMSGE | First Unit Material Costs of E/V Thermal/Structure Group. |
| CMSW | Material, CFE, and Subcontract first unit cost of the Sailwing. |
| CMSWE | Material, CFE, and Subcontract Design & Development cost of the |
| | Recovery Sailwing Subsystem - E/V. |
| CMRSYS | Material, CFE, and Subcontract Design & Development cost of the |
| | non-structural Subsystems, E/V & M/M total. |
| CMSSE | First Unit Material, CFE, Subcontract costs of the Entry Vehicle. |
| CMTCE | Material, CFE, and Subcontract Design & Development cost of the |
| | Telecommunications Subsystem - E/V. |
| CMTCM | Material, CFE, and Subcontract Design & Development cost of the |
| | Telecommunications Subsystem - M/M. |
| CMTPA | Material, CFE, and Subcontract first unit cost of the Ablative |
| | Thermal Protection. |
| CMTPR | Material, CFE, and Subcontract first unit cost of the Radiative |
| | Thermal Protection. |
| CMTSTR | Material, CFE, and Subcontract First Unit Cost of Thermal/Structure |
| | Group and Launch Upper Stage Tanks E/V & M/M. |
| CMTSYS | Material, CFE, and Subcontract First Unit Cost of non-structural |
| | Subsystems E/V & M/M. |
| CMVME | Material, CFE, and Subcontract Design and Development cost of the |
| | Vernier Maneuver Subsystem - E/V. |
| CMVMM | Material, CFE, and Subcontract Design and Development cost of the |
| | Vernier Maneuver Subsystem - M/M. |
| COPAM | Operational Labor Cost of AGE Maintenance - S/C. |
| COPFM | Operational Labor Cost of Facility Maintenance - S/C. |
| COPLAS | Launch Area Support Labor Cost. |
| OD OO | |

First Unit Production cost of the Crew Station, E/V.

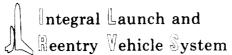


First Unit Production Labor Cost (excludes Final Assembly and CPE Checkout); E/V. CPE = CPSE + CPSYSE. CPFC First Unit Production Cost of Final Assembly and Checkout - E/V. **CPFCM** First Unit Production Cost of Final Assembly and Checkout - M/M. CPHP First Unit Production cost of the Hydraulics and Pneumatics. **CPLA** First Unit Production cost of the Landing Assist Solid Rocket. CPLG First Unit Production cost of the Landing Gear. CPM Prime Contractor First Unit Production Labor Cost (excludes Final Assembly and Checkout) - M/M. CPM = CPSM + CPSYSM. CPO First Unit Production Cost of the Ordnance, E/V. CPP First Unit Production cost of the Parachute. RDT&E Labor Cost for Launch Site Facility Activation. **CPRFLA CPRFRS** RDT&E Labor Cost for Recovery Site Facilities. First Unit Production cost of the Aerodynamic Control Surfaces. **CPSAC CPSCS** First Unit Production cost of the Crew Section Structure. **CPSGE** First Unit Production Costs of the E/V Thermal/Structural Group. CPSE First Unit Production Cost of Thermal/Structure Group and Launch Upper Stage tanks - E/V. CPSM First Unit Production Cost of Thermal/Structure Group - M/M. CPSW First Unit Production Cost of the Sailwing. **CPSYSE** First Unit Production Cost of non-structural Subsystems - E/V. **CPSYSM** First Unit Production Cost of non-structural Subsystems - M/M. **CPTPA** First Unit Production Cost of the Ablative Thermal Protection. **CPTPR** First Unit Production Cost of the Radiative Thermal Protection. CRAGR RDT&E Total Recurring Initial AGE Cost. CRE Total RDT&E Prime Contractor Engineering Cost - S/C. CRFAC RDT&E Facility Cost. CRPLSA RDT&E Launch Site Peculiar AGE Labor Cost. CRSSF Labor Cost of Remote Site Static Fire Testing of the Launch Upper Stage Propulsion. CSEE First Unit Sustaining Engineering Cost - E/V. First Unit Sustaining Engineering Cost - M/M. CSEM First Unit Sustaining Tooling Cost - E/V. CSTE First Unit Sustaining Tooling Cost - M/M. CSTM CTP First Unit Production Cost - S/C = CPSE + CPSM + CPSYSE + CPSYSM +

CPFC + CPFCM.

Design and Development Tooling Cost of the Simple Adapter Structure. CTRA CTRCPE Design and Development Tooling Cost of the Cargo/Propulsion Section Structure - E/V. CTRCPM Design and Development Tooling Cost of the Cargo/Propulsion Section Structure - M/M. CTRCSE Design and Development Tooling Cost of the Crew Section Structure. CTRLG Design and Development Tooling Cost of the Landing Gear Subsystem. CTRLT Design and Development Tooling Cost of the Launch Escape Tower Subsystem. CTRTE D&D Tooling Cost of the Launch Upper Stage External Propellant Tanks. CTRTI D&D Tooling Cost of the Launch Upper Stage Internal Propellant Tanks. CTRTPE D&D Tooling Cost for the Ablative Thermal Protection Subsystem. E EKWH Total energy in kilowatt hours of the fuel cell system in the E/V. EKWHM Total energy in kilowatt hours of the fuell cell system in the M/M. E2S Existing recovery site network switch. F FECABL Thrust in lbs. of Entry Attitude Control Subsystem pressure fed ablative cooled engine. FECRAD Thrust in lbs. of Entry Attitude Control Subsystem pressure fed radiation cooled engine. FLRGC Thrust in 1bs. of regenerative pump fed cryogenic engine - Launch Upper Stage Subsystem. FLRGS Thrust in lbs. of regenerative pump fed storable engine - Launch Upper Stage Subsystem. FMABL Thrust in 1bs. of pressure fed storable ablative engine - Main Orbital Maneuver Subsystem - E/V. **FMABLM** Thrust in lbs. of pressure fed storable ablative engine - Main Orbital Maneuver Subsystem - M/M. FMRGC Thrust in lbs. of pump fed cryogenic regenerative engine - Main Orbital Maneuver Subsystem - E/V. **FMRGCM** Thrust in lbs. of pump fed cryogenic regenerative engine - Main

Orbital Maneuver Subsystem - M/M.



| volume III | Reentry Vehicle System |
|-----------------|---|
| FMRGS | Thrust in lbs. of pump fed storable regenerative engine - Main |
| | Orbital Maneuver Subsystem - E/V. |
| FMRGSM | Thrust in 1bs. of pump fed storable regenerative engine - Main |
| | Orbital Maneuver Subsystem - M/M. |
| FVDAB | Thrust in lbs. of pressure fed storable ablative secondary engine - |
| | Vernier Maneuver Subsystem - E/V. |
| FVDABM | Thrust in lbs. of pressure fed storable ablative secondary engine - |
| | Vernier Maneuver Subsystem - M/M. |
| FVDRA | Thrust in lbs. of pressure fed storable radiation secondary engine - |
| | Vernier Maneuver Subsystem - E/V. |
| FVDRAM | Thrust in lbs. of pressure fed storable radiation secondary engine - |
| | Vernier Maneuver Subsystem - M/M. |
| FVOAB | Thrust in 1bs. of pressure fed storable ablative main engine - |
| | Vernier Maneuver Subsystem - E/V. |
| FVOABM | Thrust in lbs. of pressure fed storable ablative main engine - |
| | Vernier Maneuver Subsystem - M/M. |
| FVORA | Thrust in lbs. of pressure fed storable radiation main engine - |
| | Vernier Maneuver Subsystem - E/V. |
| FVORAM | Thrust in lbs. of pressure fed storable radiation main engine - |
| | Vernier Maneuver Subsystem - M/M. |
| <u>H</u> | |
| HFT | Hot Fire Acceptance Test Switch. |
| т | |
| <u>I</u> IBV | Ballistic configuration switch for reuse modes D, E, & F. |
| ILB | Lifting Body configuration switch for reuse modes D, E, & F. |
| ITDO | Total impulse in 1b-sec. of one solid rocket motor - Deorbit |
| 1100 | Subsystem - E/V. |
| ITDOM | Total impulse in 1b-sec. of one solid rocket motor - Deorbit |
| 110011 | Subsystem - M/M. |
| ITLA | Total impulse in lb-sec. of one solid rocket motor - Landing Assist |
| 11211 | Subsystem - E/V. |
| ITLEH | · |
| T T 11/11 | Total impulse in 1b-sec. of one solid rocket motor - High Altitude Launch Escape - E/V. |
| ITLEL | - |
| TILL | Total impulse in 1b-sec. of one solid rocket motor - Low Altitude |

Launch Escape - E/V.

ITLELM Total impulse in lb-sec. of one solid rocket motor - Low Altitude Launch Escape - M/M.

<u>K</u>

KACPE Access Area Factor - Cargo/Propulsion Section - E/V - Used in Design & Development Engineering.

KACPME Access Area Factor - Cargo/Propulsion Section - M/M - Used in Design & Development Engineering.

KACPMP Access Area Factor - Cargo/Propulsion Section - M/M - Used in First Unit Production & Material, CFE, & Subcontract.

KACPMT Access Area Factor - Cargo/Propulsion Section - M/M - Used in Design & Development Tooling.

KACPP Access Area Factor - Cargo/Propulsion Section - E/V - Used in First Unit Production & Material, CFE, & Subcontract.

KACPT Access Area Factor - Cargo/Propulsion Section - E/V - Used in Design Development Tooling.

KDCSE Access Area Factor - Crew Section - E/V - Used in Design & Development Engineering.

KACSP Access Area Factor - Crew Section - E/V - Used in First Unit Production.

KACST Access Area Factor - Crew Section - E/V - Used in Design & Development Tooling.

KCCP Configuration Complexity Factor - Cargo/Propulsion Section - E/V - Used in Design & Development Engineering.

KCCS Configuration Complexity Factor - Crew Section - E/V - Used in Design & Development Engineering.

KCT Configuration Complexity Factor - E/V - Used in Design & Development Tooling.

KCWT Wind Tunnel vehicle configuration complexity factor.

KDCP Density Factor - Cargo/Propulsion Section - E/V.

KDCPM Density Factor - Cargo/Propulsion Section - M/M.

KDCS Density Factor - Crew Section - E/V.

KECON Economic Escalation Factor.

KECSC Environmental Control Subsystem - Cryogenic gas indicator and percent of subsystem in E/V.

| | ∫ Integral Launch and |
|------------|------------------------|
| Volume III | Reentry Vehicle System |

| KECSCM | Environmental Control Subsystem - Cryogenic gas indicator and |
|--------|---|
| | percent of subsystem in M/M. |
| KECSS | Environmental Control Subsystem - Storable gas indicator and |
| | percent of subsystem in E/V. |
| KECSSM | Environmental Control Subsystem - Storable gas indicator and |
| | percent of subsystem in M/M. |
| KENGR | Engineering Labor Rate - Dollars per manhour. |
| KLRS | Remote Site Labor Rate - Dollars per manhour. |
| KMACSP | Type of Material and Construction Complexity Factor - Aerodynamic |
| | Control Surfaces. |
| KMAP | Type of Material and Construction Complexity Factor - Simple Adapter. |
| KMCPMP | Type of Material and Construction Complexity Factor - Cargo/ |
| | Propulsion Section - M/M. |
| KMCPP | Type of Material and Construction Complexity Factor - Cargo/ |
| | Propulsion Section - E/V. |
| KMCS | Material, CFE, & Subcontract Economic Escalation Factor. |
| KMCSP | Type of Material and Construction Complexity Factor - Crew Section - |
| | E/V. |
| KMTPA | Type of Material Complexity Factor - Ablative Thermal Protection |
| | Subsystem - E/V. |
| KMTPR | Type of Material Complexity Factor - Radiative Thermal Protection |
| | Subsystem - E/V. |
| KPRL | Type of propellant factor - cost per pound of thrust for varying |
| | propellants. Used in Design and Development - Launch Upper Stage. |
| KPRL1 | Type of propellant factor - cost per pound of thrust for varying |
| | propellants. Used in Static Fire Qualification Test. |
| KPRL2 | Type of propellant factor - cost per pound of thrust for varying |
| | propellants. Used in Static Fire Acceptance Test. |
| KPRLC | Type of propellant factor - differences in first unit cost between |
| | cryogenic engines. LOX/LH $_2$ vs. F_2 /LH $_2$. |
| KPRLUC | Type of propellant factor - differences in Design & Development |
| | cost between cryogenic engines. LOX/LH $_2$ vs. F_2/LH_2 . |
| KPRMF | Type of propellant factor - storable or cryogenic, for fuel tank |
| | cost - Main Orbital Maneuver - First Unit - E/V. |
| KPRMFM | Type of propellant factor - storable or cryogenic, for fuel tank |
| | cost - Main Orbital Maneuver - First Unit M/M. |
| | |

KPRMO Type of propellant factor storable or cryogenic, for oxidizer tank

cost - Main Orbital Maneuver - First Unit - E/V.

KPRMOM Type of propellant factor - storable or cryogenic, for oxidizer

tank cost - Main Orbital Maneuver - First Unit - M/M.

KPROD Production Labor Rate - Dollars per Manhour.

KPS Type of propellant used in the cargo/propulsion section

structure - E/V.

KPT Type of propellant used in the Launch Upper Stage Propellant Tanks.

KRED Redundancy factor - Entry Attitude Control Subsystem.

KSA Panel Shape Complexity Factor - Ablative Thermal Protection

Subsystem.

KSR Panel Shape Complexity Factor - Radiative Thermal Protection

Subsystem.

KTOOL Tooling Labor Rate - Dollars per manhour.

L

LEVDAM Material, CFE, & Subcontract - Design & Development - Ablative

secondary engine locator - Vernier Maneuver - M/M.

LEVDRM Material, CFE, & Subcontract - Design & Development - Radiation

secondary engine locator - Vernier Maneuver - M/M.

LEVOAM Material, CFE, & Subcontract - Design & Development - Ablative

secondary engine locator - Vernier Maneuver - M/M.

LEVORM Material, CFE, & Subcontract - Design & Development - Radiation

secondary engine locator - Vernier Maneuver - M/M.

LLM Land landing mode switch.

LREECA Material, CFE, & Subcontract - Design & Development - Ablative

engine locator - Entry Attitude Control.

LREECR Material, CFE, & Subcontract - Design & Development - Radiation engine

locator - Entry Attitude Control.

LREMA Material, CFE, & Subcontract - Design & Development - Ablative

engine locator - Main Orbital Maneuver - E/V.

LREMAM Material, CFE, & Subcontract - Design & Development - Ablative engine

locator - Main Orbital Maneuver - M/M.

LREMC Material, CFE, & Subcontract - Design & Development - regenerative

cryogenic engine locator - Main Orbital Maneuver - E/V.

Integral Launch and Beentry Vehicle System

LREMCM Material, CFE, & Subcontract - Design & Development - regenerative

cryogenic engine locator - Main Orbital Maneuver - M/M.

LREMS Material, CFE, & Subcontract - Design & Development - regenerative

storable engine locator - Main Orbital Maneuver - E/V.

LREMSM Material, CFE, & Subcontract - Design & Development - regenerative

storable engine locator - Main Orbital Maneuver - M/M.

LREVDA Material, CFE, & Subcontract - Design & Development - ablative

secondary engine locator - Vernier Maneuver - E/V.

LREVDR Material, CFE, & Subcontract - Design & Development - ablative

secondary engine locator - Vernier Maneuver - E/V.

LREVOA Material, CFE, & Subcontract - Design & Development - ablative

main engine locator - Vernier Maneuver - E/V.

LREVOR Material, CFE, & Subcontract - Design & Development - radiation main

engine locator - Vernier Maneuver - E/V.

LSTOA Airdrop system test operations locator.

LTS Land Transportation Switch.

M

M Number of men in spacecraft.

MBV Ballistic configuration switch - reuse modes A, B, & C.

MLB Lifting Body configuration switch - reuse modes A, B, & C.

MT Mission duration in days.

N

NB Number of batteries in E/V.

Number of batteries in M/M. NBM

Number of engines in integral propulsion. NE

NEECAB Number of ablative engines in the Entry Attitude Control Subsystem.

NEECRA Number of radiation engines in the Entry Attitude Control

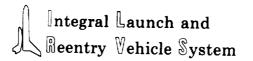
Subsystem.

NELRGC Number of regenerative cryogenic engines in the Launch Upper Stage

Subsystem.

NELRGS Number of regenerative storable engines in the Launch Upper Stage

Subsystem.



| NEMAB | Number | of | ablative | engines | in | the | Main | Orbital | Maneuver | Subsystem | _ | F/V | , |
|-------|--------|----|----------|---------|----|-----|------|---------|----------|-----------|---|-----|---|
|-------|--------|----|----------|---------|----|-----|------|---------|----------|-----------|---|-----|---|

NEMABM Number of ablative engines in the Main Orbital Maneuver Subsystem - M/M.

NEMRCM Number of regenerative cryogenic engines in the Main Orbital Maneuver Subsystem - M/M.

NEMRGC Number of regenerative cryogenic engines in the Main Orbital Maneuver Subsystem - E/V.

NEMRGS Number of regenerative Storable engines in the Main Orbital Maneuver Subsystem - E/V.

NEMRSM Number of regenerative storable engines in the Main Orbital Maneuver Subsystem - M/M.

NEVDAB Number of ablative secondary engines in the Vernier Maneuver Subsystem - $\mathrm{E/V}$.

NEVDAM Number of ablative secondary engines in the Vernier Maneuver Subsystem - $\mathrm{M/M}$.

NEVDRA Number of radiative secondary engines in the Vernier Maneuver Subsystem - $\mathrm{E/V}$.

NEVDRM Number of radiative secondary engines in the Vernier Maneuver Subsystem - $\mathrm{M/M}$.

NEVOAB Number of ablative main engines in the Vernier Maneuver Subsystem - E/V.

NEVOAM Number of ablative main engines in the Vernier Maneuver Subsystem - M/M.

NEVORA Number of radiation main engines in the Vernier Maneuver Subsystem - E/V.

NEVORM Number of radiation main engines in the Vernier Maneuver Subsystem - M/M.

NFC Number of fuel cells in the E/V.

NFCM Number of fuel cells in the M/M.

NMDO Number of solid rocket motors in the Deorbit Subsystem - E/V.

NMDOM Number of solid rocket motors in the Deorbit Subsystem - M/M.

NMLA Number of solid rocket motors in the Landing Assist Subsystem.

NMLEH Number of solid rocket motors in the High Altitude Launch Escape Subsystem.

NMLEL Number of solid rocket motors in the Low Altitude Launch Escape Subsystem - $\mathrm{E/V}$.

NMLELM Number of solid rocket motors in the Low Altitude Launch Escape Subsystem - M/M.

NR Number of refurbishments.

```
Number of existing recovery sites.
NS
          Number of fuel and oxidizer tanks in the Entry Attitude Control Subsys.
NTEAC
          Number of external tanks in the Launch Upper Stage Subsystem.
NTEXT
          Number of secondary fuel tanks in the Main Orbital Maneuver Subsys. - \mathrm{E}/\mathrm{V}.
NTMDF
          Number of secondary fuel tanks in the Main Orbital Maneuver Subsys. - \mathrm{M/M}.
NTMDFM
          Number of secondary oxidizer tanks in the Main Orbital Maneuver
NTMDO
          Subsystem - E/V.
          Number of secondary oxidizer tanks in the Main Orbital Maneuver
MTMDOM
           Subsystem - M/M.
           Number of main fuel tanks in the Main Orbital Maneuver Subsys. - E/V.
NTMOF
          Number of main fuel tanks in the Main Orbital Maneuver Subsys. - M/M.
NTMOFM
           Number of main oxidizer tanks in the Main Orbital Maneuver Subsys. - \mathrm{E}/\mathrm{V}.
NTMOO
           Number of main oxidizer tanks in the Main Orbital Maneuver Subsys. - \mathrm{M/M}.
NTMOOM
           Number of secondary fuel and oxidizer tanks in the Vernier Maneuver
NTVMD
           Subsystem - E/V.
           Number of secondary fuel and oxidizer tanks in the Vernier Maneuver
NTVMDM
           Subsystem - M/M.
           Number of main fuel and oxidizer tanks in the Vernier Maneuver
NTVMO
           Subsystem - E/V.
           Number of main fuel and oxidizer tanks in the Vernier Maneuver
NTVMOM
           Subsystem - M/M.
P
           Launch Upper Stage Subsystem indicator for high chamber pressure
 PCLRGC
           cryogenic engines.
           Launch Upper Stage Subsystem indicator for high chamber pressure
 PCLRGS
           storable engines.
           Power output per fuel cell - kilowatts - E/V.
 PKW
           Power output per fuel cell - kilowatts - M/M.
 PKWM
           Operational program life in years from the first launch to the last.
 PL
           Ablative average panel size in square feet - Thermal Protection Subsys.
 PSA
```

Q

PSR

QA1 Quantity of airdrop test vehicles.

QAGE1 Quantity of equivalent sets of initial AGE.

QAGE2 Quantity of equivalent sets of additional AGE.

Radiative average panel size in square feet - Thermal Protection Sys.

| Volume III | Integral Launch and Report NO. MDC E0049 NOVEMBER 1969 |
|------------|--|
| QF1 | Quantity of boosted flight test vehicles. |
| QF2 | Quantity of boosted flight test flights. |
| QG1 | Quantity of ground test vehicles - E/V . |
| QG2 | Quantity of ground test vehicles - M/M. |
| QI1 | Total quantity of boosted flight test and investment vehicles. |
| QI2 | Total quantity of boosted flight test and investment flights. |
| <u>s</u> | |
| SWTPA | Total wetted area in sq. feet of ablative thermal protection panels. |
| SWTPR | Total wetted area in sq. feet of radiative thermal protection panels. |
| <u>T</u> | , and the particular p |
| ± TDS | Test deletion switch PEEDS - 2 mpg 1, pupps / 2 mpg |
| TSC | Test deletion switch REFPC = 3, TDS = 1; REFPC \(\neq 3, \text{TDS} = 0. \) |
| 150 | Total Spacecraft First Unit cost (includes sustaining engr., |
| | sustaining tooling, production, and material, CFE, subcontract.) |
| <u>U</u> | |
| USP | Integral Upper Stage Propulsion Switch. |
| <u>v</u> | |
| VLM | Vertical landing mode switch. |
| VMDF | Volume of one secondary fuel tank in the Main Orbital Maneuver |
| | Subsystem - E/V, Cubic Feet. |
| VMDFM | Volume of one secondary fuel tank in the Main Orbital Maneuver |
| | Subsystem - M/M, Cubic Feet. |
| VMDOX | Volume of one secondary oxidizer tank in the Main Orbital Maneuver |
| | Subsystem - E/V, Cubic Feet. |
| VMDOXM | Volume of one secondary oxidizer tank in the Main Orbital Maneuver |
| | Subsystem - M/M, Cubic Feet. |
| VMOF | Volume of one main fuel tank in the Main Orbital Maneuver Subsystem - |
| | E/V, Cubic Feet. |
| VMOFM | Volume of one main fuel tank in the Main Orbital Maneuver Subsystem - |
| | M/M, Cubic Feet. |

Volume of one main oxidizer tank in the Main Orbital Maneuver

Volume of one main oxidizer tank in the Main Orbital Maneuver

Subsystem - E/V, Cubic Feet.

Subsystem - M/M, Cubic Feet.

Staging Velocity, feet per second.

VMOOX

VMOOXM

VS

VTEAC Volume of one fuel or oxidizer tank in the Entry Attitude Control Subsystem, Cubic Feet.

VTVMD Volume of one secondary fuel or oxidizer tank in the Vernier Maneuver Subsystem - E/V, Cubic Feet.

VTVMDM Volume of one secondary fuel or oxidizer tank in the Vernier Maneuver Subsystem - M/M, Cubic Feet.

VTVMO Volume of one main fuel or oxidizer tank in the Vernier Maneuver Subsystem - E/V, Cubic Feet.

VTVMOM Volume of one main fuel or oxidizer tank in the Vernier Maneuver Subsystem - M/M, Cubic Feet.

M

WB Battery weight, pounds - E/V.
WBM Battery weight, pounds - M/M.

WCDPC Total Weight in pounds of the E/V at Parachute deployment.

WCDSW Total Weight in pounds of the E/V at Sailwing deployment.

WCS Weight in pounds of Crew Station Subsystem - E/V. WCSM Weight in pounds of Crew Station Subsystem - M/M.

WDEV Total Dry weight in pounds of Entry Vehicle subsystems and structure.

WDMM Total Dry weight in pounds of Mission Module subsystems and structure.

WDO Dry weight in pounds of Solid Deorbit Subsystem - E/V. WDOM Dry weight in pounds of Solid Deorbit Subsystem - M/M.

WEAC Dry weight in pounds of Entry Attitude Control Subsystem.

WECLVM Dry weight in pounds of Entry Attitude Control Subsystem-lines, valves, and miscellaneous.

WECS Dry weight in pounds of Environmental Control Subsystem - E/V.

WECSM Dry weight in pounds of Environmental Control Subsystem - M/M.

WEPD Weight in pounds of Electrical Power Distribution Subsystem - E/V.

WEPDM Weight in pounds of Electrical Power Distribution Subsystem - M/M.

WFC Weight in pounds of Fuel Cell Subsystem - E/V.

WFCM Weight in pounds of Fuel Cell Subsystem - M/M.

WFE Dry weight in pounds of Furnishings & Equipment subsystem.

WFOC Bulk weight of FLOX/CH4 in pounds per launch.

WGC Weight in pounds of the Guidance & Control Subsystem + $\mathrm{E/V}$.

WGCM

Weight in pounds of the Guidance & Control Subsystem - M/M.

| WHPN | Weight | in | pounds | of | the | Hydraulics | and | Pneumatics | Subsystem. |
|------|--------|----|--------|----|-----|------------|-----|------------|------------|
|------|--------|----|--------|----|-----|------------|-----|------------|------------|

WLA Dry weight in pounds of the Landing Assist Subsystem.

WLESE Dry weight in pounds of the Launch Escape Motor Subsystem - E/V.

WLESEM Dry weight in pounds of the Launch Escape Motor Subsystem - M/M.

WLEXT Dry weight in pounds of the one external tank in the Launch Upper Stage Subsystem. (Additional tanks are exact duplicates.)

WLFH Bulk weight of F_2/H_2 in pounds per launch.

WLG Weight in pounds of the Landing Gear Subsystem.

WLINTS Dry weight in pounds of the spherical tank in the Launch Upper Stage Subsystem.

WLINTT Dry weight in pounds of the torroidal tank in the Launch Upper Stage Subsystem.

WLLVM Dry weight in pounds of the lines, valves, & miscellaneous of the Launch Upper Stage Subsystem.

WLOH Bulk weight of $0_2/H_2$ in pounds per launch.

WLUSE Dry weight in pounds of the engine, lines, valves, & miscellaneous of the Launch Upper State Subsystem.

WMLVM Dry weight in pounds of the lines, valves, & miscellaneous of the Main Maneuver Subsystem - E/V.

WMLVMM Dry weight in pounds of the lines, valves, & miscellaneous of the Main Maneuver Subsystem - M/M.

WMOM Dry weight in pounds of the Main Maneuver Subsystem - E/V.

WMOMM Dry weight in pounds of the Main Maneuver Subsystem - M/M.

WOBC Weight in pounds of the Onboard Checkout Subsystem - E/V.

WOBCM Weight in pounds of the Onboard Checkout Subsystem - M/M.

WORD Weight in pounds of the Ordnance Subsystem - E/V.

WORDM Weight in pounds of the Ordnance Subsystem - M/M.

WPLUS Total weight in pounds of the propellant in the Launch Upper Stage Subsystem.

WRPC Weight in pounds of the Parachute Subsystem.

WRSS Dry weight in pounds of the Reactant Supply Subsystem - E/V.

WRSSM Dry weight in pounds of the Reactant Supply Subsystem - M/M.

WRSW Weight in pounds of the Sailwing Subsystem.

WSA Weight in pounds of the simple adapter structure - includes mounting structure.

| WSACSP | Weight in pounds of the Aerodynamic Control Surfaces Structure - |
|--------|--|
| | excludes all thermal protection. |

WSCPET Weight in pounds of the Cargo/Propulsion Section Structure - E/V - excludes ablative thermal protection, includes radiative thermal protection, and mounting structure.

WSCPM Weight in pounds of the Cargo/Propulsion Section Structure - M/M, includes mounting structure.

WSCPP Weight in pounds of the Cargo/Propulsion Section Structure - E/V - excludes all thermal protection & aerodynamic control surfaces, includes mounting structure.

WSCSET Weight in pounds of the Crew Section Structure - excludes ablative thermal protection, includes radiative thermal protection and mounting structure.

WSCSP Weight in pounds of the Crew Section Structure - excludes all thermal protection and aerodynamic control surfaces, includes mounting structure.

WSLET Weight in pounds of the launch escape tower structure.

WSTO Bulk weight of NTO/A-50 in pounds per launch.

WT Launch Vehicle thrown weight capability in thousands of pounds (Due East ETR Launch, $i = 28.5^{\circ}$).

WTC Weight in pounds of the Telecommunications Subsystem - E/V.

WTCM Weight in pounds of the Telecommunications Subsystem - M/M.

WVLVMM Dry weight in pounds of the lines, valves, & miscellaneous of the Vernier Maneuver Subsystem - M/M.

WVM Dry weight in pounds of the Vernier Maneuver Subsystem - E/V.

WVMLVM Dry weight in pounds of the lines, valves & miscellaneous of the Vernier Maneuver Subsystem - E/V.

WVMM Dry weight in pounds of the Vernier Maneuver Subsystem - M/M.

WWC Dry weight in pounds of the Water Cooling Subsystem.

<u>X</u>

XLC Learning curve exponent (eg. 85% L.C. exponent is .766).

4.0 SUPPORTING RESEARCH AND TECHNOLOGY PLAN

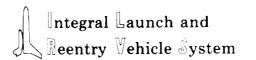
The purpose of this plan is to report those supporting research and technologies that were identified during the preliminary definition phase of the two-stage fully reusable system study. Those supporting research and technology areas considered essential or significant to the orderly development of the Orbiter and Carrier vehicles in order to produce an operational system by mid-1976 were identified. This effort should be expanded during the Phase B and C.

The costs associated with the development and operation of space systems require that any problems in the systems' performance, effectivness, and cost be resolved in a systemmatic and timely manner. These problems should be resolved to the point where the "best" solution is at least apparent prior to the date when a committment must be made for system development. These solutions can usually be obtained through the use of one or all of the following: Analytic Studies, Engineering Analyses, Experimental Tests.

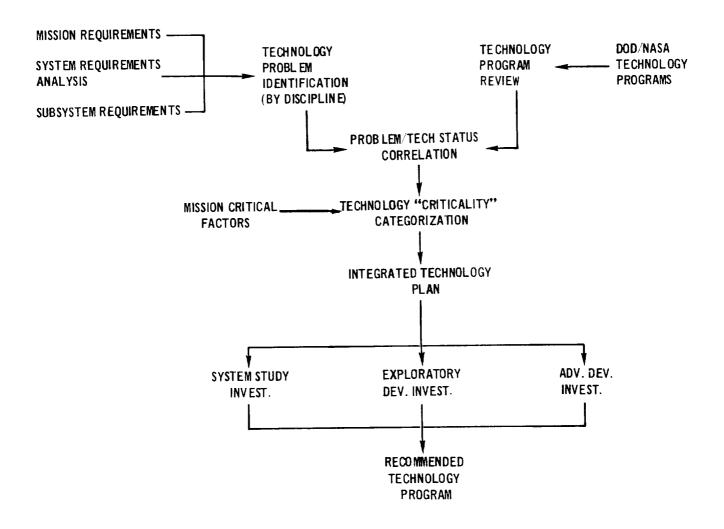
The study has revealed certain technology problem areas, identified within the technical disciplines during the conceptual design and performance phases. Some of these are "feasibility" type requiring supporting research work to prove or disprove feasibility. Others are development type requiring supporting research work to assist the development mechanization. A description of these problems follow later, together with plans for their resolution.

The Plans presented here have as their primary objective the identification of system oriented programs which should bring the required technologies to an acceptable state of development.

- 4.1 <u>Technology Analysis Methodology</u> The technology analysis methodology recommended for Phase B is shown in Figure 4-1. The sequence of activities shown will enable the contractor to:
 - O Apply the technology requirements derived during Phase B to programs currently being pursued, and to establish the degree of added effort necessary to achieve the performance requirements defined for the subsystem involved.
 - O Determine the degree of criticality in each technology/subsystem discipline by assessing the potential impact that failure to resolve the technology problem might have on:



TECHNOLOGY ANALYSIS METHODOLOGY



- A. Mission operational feasibility
- B. System design and performance
- C. System development and operating costs
- o Establish the types (analysis or test) of pre-Phase C study or development effort in each technology area.
- o Formulate an integrated technology program encompassing all of the areas of concern defined above.
- 4.2 Approach The approach used in evolving this supporting research and technology plan was to (a) identify the requirements imposed by the vehicles design, development, subsystems and operations and convert these requirements into supporting research and technology problems; (b) identify alternate approaches to establish the feasibility of satisfying the requirements with existing systems or techniques; (c) categorize each problem area as being essential, significant, refinement or indirect to the orderly development of the system; (d) define a proposed technical approach for resolving the essential and significant technology categories; and (e) establish preliminary schedules and costs for resolving these problem areas.
- 4.3 <u>Definition of Terms</u> Each supporting research or technology area was identified as being in one of four categories; essential, significant, refinement, and indirect. <u>Essential</u> is defined as that research or technology that requires a solution prior to the design of the vehicles. This involves analytic studies, engineering analysis or experimental effort to achieve engineering developments that have not been sufficiently demonstrated in the laboratory. <u>Significant</u> supporting research and technologies are those that have an effect on performance or safety that outweighs the cost of attaining the solution. Supporting research and technologies categorized as a <u>refinement</u> include those having a desirable performance or safety effect but cannot be justified because of the cost. <u>Indirect</u> technologies are defined as those that could not be solved within the time frame of this program. Solutions to problems in the latter two categories would be applicable to future generation vehicles and are therefore not included in this report.

A summary of the essential and significant technologies, the alternatives and the effect of these alternatives are shown in Table 4-1. Areas identified as "essential" and present the highest risk to the program require immediate initiation

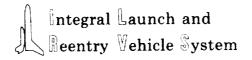


Table 4-1

SUMMARY OF TECHNOLOGIES

| TECHNOLOGY | ALTERNATIVE | EFFECT OF ALTERNATIVE |
|---|--|--|
| ESSENTIAL | | |
| • CONFIGURATION EVALUATION | NO ALTERNATIVE | |
| BOUNDARY LAYER TRANSITION AND TURBULENT HEATING | CONSERVATIVE HEATING ESTI- MATES | INCREASED WEIGHT AND COSTS |
| THERMAL PROTECTION – STRUCTURAL SYSTEM | OVER DESIGN TO ASSURE PAY- Load requirements | INCREASED WEIGHT AND COSTS |
| • TD-NiCr | COATED COLUMBIUM | POSSIBLE INCREASED WEIGHT BUT LESS RESEARCH COST |
| HARDENED COMPACTED FIBERS | COATED COLUMBIUM | POSSIBLE INCREASED WEIGHT BUT LESS RESEARCH COST |
| • HIGH P _C ENGINE | NO ALTERNATIVE | |
| SELF TEST FOR ON-BOARD CHECKOUT SIGNIFICANT | MODIFIED SYSTEM USING GROUND CHECKOUT EQUIPMENT | COMPLICATED INTERFACE TO SPACECRAFT W/GROUND CONTROLLERS AND GROUND SUPPORT EQUIPMENT |
| INTEGRATED AVIONICS DEMONSTRATION | CONVENTIONAL SUBSYSTEM APPROACH | INCREASED WEIGHT AND COST |
| ● DATA BUS | USE HARDWIRE INTERFACE CON- NECTIONS | INCREASED WEIGHT; DECREASED FLEXIBILITY; INCREASED CHECKOUT TIME |
| ELECTRONIC CONTROLS AND DISPLAYS | NO ALTERNATIVE | |
| NONCOOPERATIVE RENDEZ- VOUS | USE AIRCRAFT RADAR TECH- NOLOGY | HIGH POWER REQUIREMENTS |
| • GASEOUS 0 ₂ /H ₂ ACS | MONOPROPELLANT OR STOR- ABLE BIPROPELLANT | POSSIBLY HIGHER MAINTENANCE |

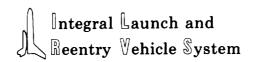


Table 4-1
SUMMARY OF TECHNOLOGIES (Continued)

| TECHNOLOGY | ALTERNATIVE | EFFECT OF ALTERNATIVE |
|---|--|---|
| SIGNIFICANT (Continued) | | |
| CRYOGENIC INSULATION | CURRENT S-O-T-A INSULATIONS | INCREASED WEIGHT AND COST |
| • INTEGRAL TANK DESIGN | CURRENT SEPARATE AIRFRAME AND TANK STRUCTURE | HEAVIER, LESS VOLUMETRIC EFFICIENCY |
| • AUTOMATIC LANDING | UPGRADE EXISTING SYSTEM | NO ALL WEATHER CAPABILITY |
| ● ENTRY ENERGY MANAGEMENT | USE PATH CONTROLLER TRA - JECTORY TECHNIQUES | NOT COMPATIBLE WITH LATERAL MANEUVERING RE- QUIREMENTS OR PILOT IN THE LOOP |
| AIRBREATHING ENGINE ORBITAL STORAGE | USE PRESSURIZED ENGINE COM- Partments for Engine Storage | INCREASED WEIGHT AND COST |
| • COATED REFRACTORY METALS | USE HCF | CONSIDERABLE R&D TO DE- TERMINE MATERIAL PROPER- TIES & MANUFACTURING TECHNIQUES |

or expansion and are listed in Table 4-1. These items are essential because design information is required by Phase D go-ahead. Failure of any one of these elements could seriously jeopardize the overall program.

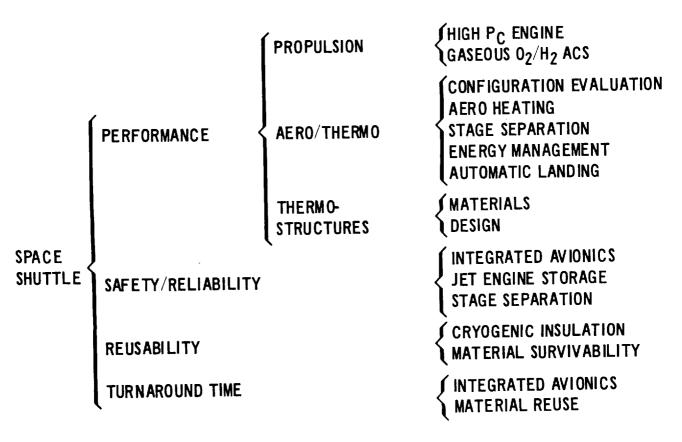
4.4 Technology Requirements - The next two figures shown the relationship between the supporting research and technology requirements and the performance and operational parameters of the space shuttle system and how these technologies relate to the various study phases. It is shown in Figure 4-2 that some technological problem areas have an effect on more than one operational or performance parameter. In Figure 4-3, Technology Flow, an attempt was made to group the research and technology areas into those primarily affecting the design phase and those having a major impact on development and vehicle fabrication. Configuration evaluation, shown as a continuing requirement, requires that considerable wind tunnel testing be accomplished for the Carrier and for the integrated configuration. The Orbiter has had many hours of test time so additional wind tunnel tests for this configuration would be minimal. It is estimated that approximately 9,000 - 10,000 hours of wind tunnel testing should be accomplished prior to Phase D go-ahead. This includes configuration analysis and definition tests of the Carrier, limited additional testing of the Orbiter (primarily heat transfer data and low speed tests with the "strap on" wing configuration) and tests of the launch configuration to determine flow interference, heating, and separation dynamics.

High Pc engine development is included as an essential and pacing requirement. However, this technology is not costed because the problems associated with this development are currently being studied in the XLR-129 program.

Development of TPS materials with high reuse potential requiring minimum inspection is one of the most important elements in achieving quick ground turnaround. Each of the material development technologies, including TD Ni Cr, hardened compacted fibers, coated refractory metals, and cryogenic insulations would include reuse potential as an important part of the study.

4.5 <u>Plans and Schedules</u> - This section contains the schedule, description of the problem area, the proposed approach to study the problem, alternatives and the cost estimate for each of the identified supporting research and technologies.

TECHNOLOGY TREE



ILRVS 481F

TECHNOLOGY FLOW

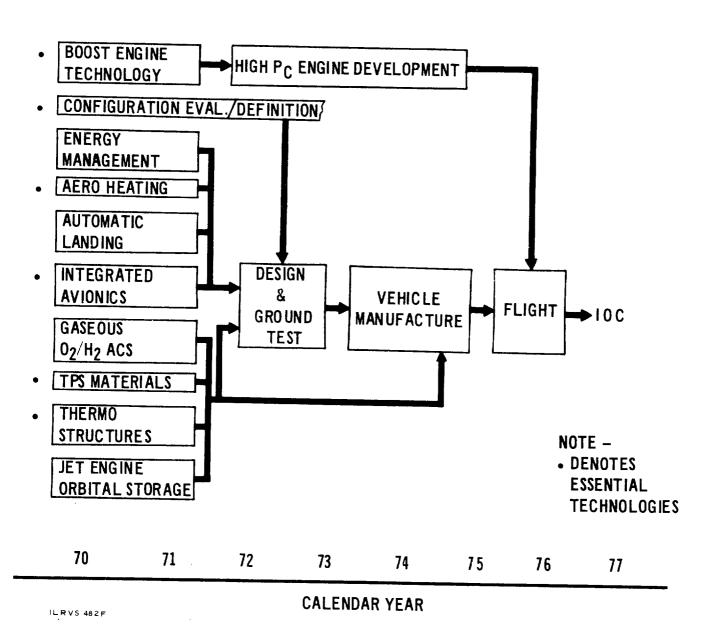


Figure 4-3

Integral Launch and Reentry Vehicle System Volume III

REPORT NO. **MDC** E0049 NOVEMBER 1969

4.5.1 Essential Supporting Research and Technology - The first section of technology descriptions include those areas identified as essential to the Space Shuttle Program. These are critical items which require that a solution be demonstrated prior to Phase D initiation. The discussion of each subject will include a preliminary schedule, the problem description, the proposed solution, possible alternatives, and the estimated cost for the proposed approach.

CONFIGURATION EVALUATION

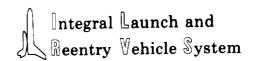
| KEY MILESTONES | 1970 | 1971 | 1972 | 1973 |
|------------------------------|---------|----------|---------|------|
| PROGRAM PHASES. | PHASE B | PHASE CT | PHASE D | |
| PREDICT FEASIBILITY | | A | | |
| CONFIGURATION ANALYSIS | | | | |
| CONFIGURATION OPTIMIZATION . | | | | |

Figure 4-4

Problem - To meet the tight schedule presented for the definition, design and development of the Space Shuttle System, leading to an IOC in mid-1976, it is imperative that a comprehensive configuration evaluation be started immediately. The Orbiter has had considerable wind tunnel and flight test time. Very limited test data are available for the Carrier configuration. Aerothermal testing data is required for the Carrier vehicle throughout the flight profile, and for the launch configuration through stage separation. Some additional testing of the Orbiter would be required to get a better definition of the heating at high Mach numbers.

Proposed Approach - Conduct analytical and experimental studies of the Carrier to determine the longitudinal, lateral and directional characteristics over the entire Mach number regime. Force and moment characteristics, static pressure distribution, dynamic characteristics, aerodynamic heating rates and shock interaction regions would be determined for the Carrier configuration for all phases of the mission. Following this configuration analysis and preliminary optimization for the Carrier, the launch configuration would be evaluated and tested to establish the pressure distribution during launch, staging and abort over the principle range of Mach number, angle of attack and dynamic pressure. Aerodynamic heating rates should be determined in the shock interaction regions as well as base heating for the Carrier to estimate thermal protection and insulation requirements.

Aerodynamic stability and control characteristics of the launch configuration is required for separation maneuver, both for normal staging and the abort situation at various velocities and altitudes.



Entry maneuver requirements should be studied and defined and aerodynamic loads, stability and control, and heat transfer problems analyzed.

Stability and control characteristics should be investigated by analysis and test for the cruise and landing phase of the Carrier vehicle. Low speed tests should be accomplished for the Orbiter with the "ferry-back" wing kit installed. A preliminary estimate indicates that 9,000-10,000 occupancy hours, utilizing a number of contractor and government facilities, will be required by Phase D go-ahead to optimize the configurations. Up to twice this number of test hours will be required during a normal Phase D program.

Alternative - There is no alternative for performing these analyses and wind tunnel tests.

Estimated Cost - \$8,000,000-\$9,000,000

Priority - Essential

BOUNDARY LAYER TRANSITION AND TURBULENT HEATING

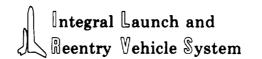
| KEY MILESTONES | 1970 | 1971 | 1972 | 1973 |
|-----------------------------------|---------|------------|---------|------|
| PROGRAM PHASES | PHASE b | I PHASE CI | PHASE D | |
| PREDICT FEASIBILITY | | _ | | |
| REVIEW CURRENT DATA | | | | |
| DETERMINE ADDITIONAL REQUIREMENTS | | | | |
| WIND TUNNEL TEST PROGRAM | | | | |
| DATA ANALYSES AND PREDICTION | | | | |
| METHODOLOGY PREPARATION | | | | |

Figure 4-5

<u>Problem</u> - An adequate criterion is required to predict boundary layer transition from laminar to turbulent flow. Such a criterion is necessary to accurately predict maximum vehicle surface temperatures and total heat inputs for use in the design of thermal protection systems for both the Orbiter and Carrier.

One method frequently used to predict transition to turbulent flow is the use of a Reynolds number based on a local boundary layer parameter such as momentum thickness. The scope of the present study did not allow for correlation of this type parameter with data available for the Orbiter. No turbulent data is available for the Carrier. Consequently, the criterion used in the present study was the onset of transition at a local Reynolds number (R) of 1.0 x 10^6 and fully developed turbulent flow occurring at R = 2.0 x 10^6 L

Most of the heat transfer data available on the Orbiter configuration is for laminar flow and low Reynolds numbers. This data indicates that flow which is turbulent at low angles of attack may become laminar at high angles of attack. However, data are not available at higher angles of attack and higher Reynolds numbers to substantiate this trend. Two transition points which can be clearly defined from the present data correspond to local Reynolds numbers of 0.5 and 0.7 x 10^6 . Since there exists some evidence that transition occurs at lower local Reynolds numbers in ground facilities than in flight, the criterion of transition onset at 1.0 x 10^6 used in the present study in adequate for preliminary design purposes. However, the present data should be supplemented to more accurately define a transition criterion for the Orbiter.



<u>Proposed Approach</u> - Supplement existing Orbiter data by testing at high Reynolds numbers. This may be accomplished by testing in an LRC facility at high angles of attack and also testing at a second facility where higher Reynolds numbers can be obtained.

Supplement Carrier LRC laminar phase change material tests by testing an instrumented model at both low and high Reynolds numbers at LRC and a second facility.

The data obtained would be used to substantiate trends indicated by present data, correlate transition criterion and evaluate the influence of transition on thermal protection system design for both the Orbiter and Carrier. Data acquired in the second facility would extend the range of Reynolds number test conditions and increase the confidence level as to the validity of the data obtained through comparison of results obtained from two facilities.

Alternative - Without the benefit of further data a conservative transition criterion must be used for both the Orbiter and Carrier. This approach will result in heavier thermal protection system weights and their associated payload penalties.

Estimated Cost - \$3,500,000 - \$4,000,000

Priority - Essential

THERMO-STRUCTURES ANALYSIS

| KEY MILESTONES | 1970 | 1971 | 1972 | |
|--------------------------|---------|----------|---------|--|
| PROGRAM PHASES | PHASE B | PHASE CI | PHASE D | |
| PREDICT FEASIBILITY | | A | | |
| DEVELOP DESIGN CRITERIA | | | | |
| SCALED COMPONENT TESTING | | | | |

Figure 4-6

<u>Problem</u> - During this study phase it was determined that the shuttle system is extremely sensitive to variations in mass fraction. For instance, for a 10% increase in first stage unit weight, the payload decreased by approximately 28% of the 25,000 lb. nominal, and a 10% increase in unit weight of both stages reduced the payload capability to one-half. At this rate the payload capability would decrease to an unacceptable level if the thermal protection system or backup structure or the combination of these increased by as much as 10%.

Proposed Approach - During the time that thermal protection materials are being studied to define material properties and design information, vehicle design criteria should be developed, the environment defined and design trade studies conducted. From these studies promising design concepts should be selected for the range of requirements and elements of representative scaled structural sections, including the TD-NiCr and HCF thermal protection materials, fabricated and tested under simulated thermal loading conditions for the various mission phases. During these tests data on design, weights, reusability, reliability and cost should be developed along with improved analytical methods. This is considered a minimum study effort prior to Phase D.

Alternative - Pay an increased penalty in weight and cost because of a requirement to over-design in order to assure the payload capability.

Estimated Cost - \$4,000,000-\$6,000,000

Priority - Essential

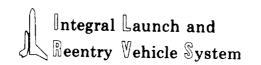
TD NICT MATERIAL DEVELOPMENT

| KEY MILESTONES | 1970 | 1971 | 1972 |
|---|---------|----------|----------|
| PROGRAM PHASES | PHASE B | PHASECI | PHASE D |
| FEASIBILITY PREDICTION. | | | |
| MATERIAL PROPERTIES & DESIGN INFORMATION TEST | | | |
| DESIGN & FABRICATE TEST SPECIMEN | | | : |
| CONDUCT SPECIMEN STRUCTURAL TESTS | | <u>}</u> | <u> </u> |

Figure 4-7

<u>Problem</u> - There is a requirement to verify some of the material properties and design application parameters of TD-NiCr sufficiently to assure feasibility of using the material prior to Phase C. Some of the problems include the lack of low strain creep data and the effect of time, temperature and load on mechanical properties from 1400 to 2200°F; development of process specification weld cycles for resistance welding and development of weld joint strength data; need for thin foil material properties and characteristics; and the requirement to fabricate and test full size panels.

Proposed Approach - Procure material from three production heats as primary produced 0.010 sheet and rerolled .005 and 0.010 sheet, and conduct element tests and microstructural studies to establish the effects of directionality on formability and material properties. Conduct element tests to establish the effects of time at elevated temperature and load at elevated temperature on the residual properties at elevated temperature and at room temperature. Conduct sufficient creep tests to establish design creep curves for .05%, .1% and .2% creep under cyclic and continuous exposure to 2400°F. Both the creep and elevated temperature tests will include directionality specimens identified as critical by the initial directionality tests. The final phase will be the fabrication and test of representative structural panels. In conjunction with this phase resistance welding parameters will be firmly established for a production process and sufficient properties tests conducted to design the panel to recommended minimums. Tests would be conducted to simulated flight profiles to verify the design minimums and production procedures established by element tests. These



tests will include cycling of materials at elevated temperatures and varying loads. Particular attention should be paid to creep and oxidatiation effects in terms of hardware reusability, and the effects of low temperature elongation on local panel instabilities. These data would be useful in the establishment of reuse potential and inspection procedures:

Alternative - Use coated columbium which will probablu mean an increase in the system weight.

Estimated Cost - \$1,000,000-\$1,500,000 Priority - Essential

HARDENED COMPACTED FIBERS

| KEY MILESTONES | 1970 | 1971 | 1972 |
|--------------------------------------|----------|-------------|---------|
| PROGRAM PHASES | PHASE B | I PHASE C I | PHASE D |
| PREDICT FEASIBILITY | <u> </u> | | |
| SUBSCALE DEVELOPMENT & FABRICATION | | | |
| SUBSCALE TESTING | | | |
| FULL-SCALE DEVELOPMENT & FABRICATION | | 力 | |
| FULL-SCALE TESTS & EVALUATION | ļ | | |

Figure 4-8

<u>Problem</u> - Hardened Compacted Fibers (HFC), a family of fiber based, ceramic oxide, thermal protection systems, have been studied and identified as good candidates for advanced, lightweight, thermal protection for reusable shuttle vehicles operating at temperatures up to about 2600°F. The thermal efficiency of HCF material is better than the best ablator materials thereby providing lighter weight thermal protection systems. They are also potentially reusable because they are inorganic and do not exhibit mass loss during reentry heating. However, scale-up from small specimens to full-scale heat shields and the state of development are areas of limited experience although an 18 inch diameter part was successfully fabricated. Problem areas that need investigating are possible damage caused by rain, absorption and erosion, ground handling and acoustic and mechanical vibration.

Proposed Approach - Develop various HCF systems emphasizing process reproducibility, uniformity, scale-up, attachment, methods, outer surface protection and costs. Develop and evaluate coatings. Conduct subscale tests under simulated reentry conditions using torch and plasma facility tests. Conduct mechanical and acoustic vibration tests to study reuse. Conduct thermal conductivity tests and impact tests. Selected HCF systems should be fabricated into full-scale test specimens. Evaluation of mechanical and thermal properties and optimum fabrication techniques should be conducted. These data would be useful in the establishment of inspection procedures.

<u>Alternative</u> - Use of coated refractory materials may offer a satisfactory alternate.

Estimated Cost - \$1,250,000-\$1,500,000

Priority - Essential

HIGH P_C BOOST ENGINE

| KEY MILESTONES | 1970 | 1971 | 1972 | 1973 | 1974 | 1975 | 1976 |
|---------------------------------------|-------|------------|--------|--------|------|----------|--------------------|
| PROGRAM PHASES | PHASE | SIPHASE CI | PH | ASE D | l | | |
| PREDICT FEASIBILITY | | _ | DEMONS | TRATED | | IST VERT | 1ST IOC ORBITAL |
| CURRENT XLR129 DEV. PROGRAM | | | FEASIB | LITY | | | UAL |
| NORMAL ACQUISITION PHASE DEVELOPMENT. | | ļ <u> </u> | | | | À Ì | |

Figure 4-9

<u>Problem</u> - Design and development of the main propulsion engine is one of the essential development problems of the current Space Shuttle System concept. The many technology problems embodied in the engine development are currently being studied in the XLR-129 program.

While the anticipated progress of these engine programs is expected to demonstrate feasibility in time for a normal but lengthy acquisition phase development, the problem is mentioned here to highlight the importance of maintaining an engine (and associated technologies) development program to assure demonstration of feasibility in time for an acquisition phase in late 1971.

<u>Proposed Approach</u> - (Not applicable because the research program is currently underway.)

Estimated Cost - (Not applicable.)

Priority - Essential

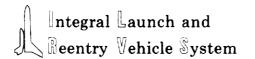
SELF-TEST FOR ON-BOARD CHECKOUT

| KEY MILESTONES | 1970 | 1971 | 1972 |
|-----------------------------------|---------|---------|---------|
| PROGRAM PHASESPREDICT FEASIBILITY | PHASE B | PHASE C | PHASE D |
| DATA REQUIREMENT ANALYSIS | | | |
| SUBSYSTEM DEFINITION | | _ | |
| BREADBOARD TESTING. | | | |

Figure 4-10

Problem - The system checkout philosophy of today is on-board checkout. Although the philosophy is sound, insufficient detail evaluation and study has been conducted. It is essential therefore, that techniques in conjunction with authentic requirements be studied. The specific problem is two-fold: (a) requirements are needed to determine the parameters to be measured in order to state that the subsystems are flightworthy, and (b) techniques are needed which can be implemented feasibly. Self-test and warning systems should be employed beginning with factory testing and continuing through the life of the vehicle. A related problem is the malfunction detection and switching required to implement multiple failure criteria. If the fail operational, fail operational, fail safe criteria is to be met for avionics subsystems, feasible techniques must be defined for malfunction detection and switching in order to properly reflect the level of redundancy, i.e., component, module, or subsystem, to be used in avionics equipment and to define the amount of equipment needed for given techniques.

<u>Proposed Approach</u> - The proposed technical approach consists of studies and breadboard demonstration. The parameters relative to each generic type equipment will be evaluated followed by identification of the parameters required to determine flightworthiness. Then techniques for development of self-test, warning, and switching within each subsystem should be defined early enough to assure standardization of subsystem interfaces and checkout philosophies. Instrumentation to perform the self-test and warning functions must be designed into each of the subsystems.

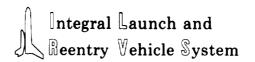


Alternative - An alternate position to development of self-test capability would be to use a modified on-board checkout approach by including ground type checkout equipment. This would complicate the interface to the spacecraft by the intervention of ground controllers, and the associated ground support equipment and auxiliary checkout stations. Regarding malfunction detection and switching to meet multiple failure criteria, the alternatives are (1) to relax the requirements for fail operational, fail operational, fail safe or (2) to use redundancy at the subsystem level or at the level where the crew can detect malfunctions and have the crew perform manual switching.

Estimated Cost - \$3,500,000 to \$4,000,000

Priority - Essential

Volume III



REPORT NO. MDC E0049 NOVEMBER 1969

4.5.2 <u>Significant Supporting Research and Technologies</u> - In the following section those supporting research and technology areas are discussed which are considered significant to the Space Shuttle System because by their solution they can enhance the system performance or safety.

INTEGRATED AVIONICS SYSTEM DEMONSTRATION

| KEY MILESTONES | 1970 | 1971 | 1972 | 1973 |
|--|---------|---------|---------|------|
| PROGRAM PHASES DEMONSTRATED FEASIBILITY | PHASE B | PHASE C | PHASE D | |
| SUBSYSTEM PERFORMANCE SPECIFICATION PREP. SUBSYSTEM BREADBOARD DEVELOPMENT | | | | |
| SIMULATION SPECIFICATIONS GROUND SIMULATIONS | | | | |
| FLIGHT SIMULATIONS | | | | |

Figure 4-11

<u>Problem</u> - A requirement exists to integrate all of the vehicle electronic systems into a simplified total system which will reduce the weight, volume requirements, power requirements and cost. Avionics systems now account for a large percentage of the development of an advanced vehicle. An integrated system would serve to eliminate some overlapping requirements experienced with the use of single avionics elements.

Proposed Approach - To assure compatible integration and subsystem design much of the subsystem performance specification preparation and breadboard development effort must be started early in the preliminary definition phase. Performance specifications must be prepared and subsystem breadboards developed and integrated into a complete breadboard. The electronically integrated subsystems would be tested in a ground based facility where forces and moments and system inertias could be simulated. Some existing hardware components from the Gemini or Apollo programs could be used in the tests. Flight simulation tests could be performed following the initial phases of the ground simulation program.

Alternative - Although there are many alternatives possible, the most direct approach is to use a conventional subsystem approach, i.e., single purpose displays, hard wire for data, etc. This alternate solution would result in increased vehicle weight and program cost and would surely result in decreased flexibility to accommodate an advanced technology space shuttle system.

Estimated Cost - \$4,000,000-\$5,000,000

DATA BUS

| KEY MILESTONES | 1970 | 1971 | 1972 |
|------------------------------|---------|---------|---------|
| PROGRAM PHASES | PHASE B | PHASE C | PHASE D |
| PREDICT FEASIBILITY | | | |
| DEFINE TECHNIQUES/INTERFACES | | | |
| PRELIMINARY DESIGN | |] | |
| BREADBOARD DEMONSTRATION | | | |

Figure 4-12

<u>Problem</u> - The weight and installation complexity of wire bundles can be drastically reduced by the use of standard interfaces and multiplexing data buses between avionic equipments. In addition to being heavy and inflexible, wire bundles are subject to electromagnetic interference and electrical shorts. Development of the standard interface circuitry and of the redundant multiplexing techniques to be employed, will allow evaluation of the implementation problems and provide a demonstration of the data bus system design. This approach will considerably reduce manufacturing and checkout time and complexity.

<u>Proposed Approach</u> - The proposed technical approach is to develop standard interface circuits and multiplexing techniques by studying, and in some cases defining, the following factors:

- Implementation techniques
- o logic complexity
- o software requirements
- o data rates and traffic patterns
- o electromagnetic compatibility
- Reliability
- o degree of subsystem interdependence
- o possibility of interface failures disabling multiplexed system
- o adaptability to redundancy
- Flexibility for interface changes
- o software changes
- o hardware changes
- Effect of interface specification and coordination

Some of the multiplexing parameters to be considered include the modulation scheme (analog, digital, time, frequency, etc.), transmission lines (shielded twisted pair, coaxial cable, fibre optics bundles), coupling methods (a.c. or d.c.) signal coding and wave shapes (RZ, NRZ, Bi-Phase, square wave, and smoothed/square wave), and word and message format (coding/decoding implications).

After the initial design is complete, a breadboard demonstration should be conducted. Since the actual space shuttle avionics equipment (e.g., digital computer, multimode radar, rate gyro package) will not be available at this time, this equipment can be simulated by static registers, computer controlled registers, or adaptations of existing equipment (such as from the Gemini program). Static registers preclude evaluations of some dynamic situations. Computer controlled registers require the availability of a computer with a flexible input-output section. Adapting existing Gemini avionics provides a good opportunity for resolving many of the significant problems.

Alternatives - Penalties for using the alternate approach of individual hard wired interface connections with non-standard interfaces are (a) wire bundle weight and installation complexity increases; (b) add-on/take-off equipment flexibility is lost; (c) manufacturing and vehicle checkout time and complexity is increased, and; (d) physical difficulties of equipment installation and removal is increased.

Estimated Cost - \$1,250,000 - \$2,000,000

ELECTRONIC CONTROLS AND DISPLAYS

| KEY MILESTONES | 1970 | 1971 | 1972 |
|-------------------------------------|---------|----------|---------|
| PROGRAM PHASES | PHASE B | PHASE C | PHASE D |
| PREDICT FEASIBILITY | | A | |
| ANALYZE REQUIREMENTS | | | |
| SUBSYSTEM PRELIMINARY DEFINITION | | □ | |
| COMPONENT BENCH & BREADBOARD TESTS_ | ļ | | |

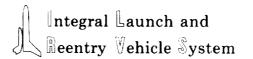
Figure 4-13

<u>Problem</u> - Electronic displays are required to provide the crew with status information at all times without having to scan the normal complement of dials, gages and switches. Complexity of the space shuttle systems and missions require that the crew be relieved of as many management decisions as possible. Although the technology is available to provide a control and display system that can perform most of the vehicle operational tasks, large improvements are required concerning the type of information displayed and the reliability of display information for inflight checkout, rendezvous and landing on multiple wide angle screens with backup redundancy.

Proposed Approach - Analyze the display requirements, make a preliminary definition of the subsystems, and develop breadboard demonstration models of a crew station display and a wide angle heads-up display. This development effort would serve to verify the all-electronic display concept and problems, to provide the development of the projection systems, and to demonstrate the equipment. The breadboard system would be tested to demonstrate the feasibility of the approach.

Alternative - None

Estimated Cost - \$2,500,000 - \$4,500,000



NON-COOPERATIVE RENDEZVOUS

| KEY MILESTONES | 1970 | 1971 | 1972 |
|------------------------------------|-----------|---------|-----------|
| PROGRAM PHASES PREDICT FEASIBILITY | _ PHASE B | PHASE C | PHASE D 3 |
| EVALUATION OF TECHNIQUES | | | |

Figure 4-14

Problem - A requirement exists to obtain a multi-mode radar which can perform the acquisition, tracking, and rendezvous in orbital operations with a non-cooperative target. A significant system engineering problem is brought about by the amount of power required (an average of 2 kw with peak power requirements 16 to 15 times that amount) to operate an existing rendezvous radar against a non-cooperative target (tracking, inspection, repair and retrieval of satellites). An on-board television system may be required along with the rendezvous radar to assist the crew during rendezvous and checkout. Alternate rendezvous techniques need to be examined with a view of enhancing the overall performance of the shuttle vehicle.

Froposed Approach - Various rendezvous techniques would be evaluated and compared for their overall impact on the vehicle and mission. Techniques to be evaluated include radar, optical, and high performance autonomous navigation systems. Develop and test a mock-up system based on the techniques evaluated as most promising considering the antenna system, protection of the system from reentry temperatures, and reliability. Consider antennas developed with heat resistant materials so that they can survive reentry environment.

Alternative - There is no alternate approach except to use technology developed for aircraft radar and design the system for the significant power requirements. State-of-the-art techniques in solid state microwave power sources do not permit attaining the power requirements for the radar.

Estimated Cost - \$500,000 - \$750,000

02/H2 ATTITUDE CONTROL PROPULSION

| KEY MILESTONES | 1970 | 1971 | 1972 |
|---------------------------------------|---------|--------------|----------|
| PROGRAM PHASES | PHASE B | PHASEC | PHASE D |
| FEASIBILITY DECISION | | A | |
| TASKS | | | |
| PREM, ANAL YSIS & SYS. REQ. DEF | | | |
| SYSTEM DESIGN ANALYSIS | | 1 | |
| COMPONENT FEASIBILITY STUDIES & TESTS | | - | } |
| SYSTEM INTEGRATION STUDIES | L | | |
| | | | <u> </u> |

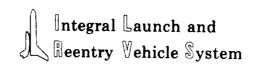
Figure 4-15

Problem - While the problem can be summarized as determining the feasibility of a low maintenance attitude control system which uses the onboard main boost engine propellants; it is in reality much more complex. There are many more specific technology problems which are interrelated and must be studied and solved together. Some of the most significant ones are: gaseous injection, reliable multicycle ignition system, thrust chamber cooling techniques, extremely high cycle life and leak tight injection valve design.

<u>Proposed Approach</u> - Prior to the definition phase conduct a study which contains four major task efforts as shown in the above schedule.

- 1) Analyze the system requirements, establish preliminary subsystem requirements, and select a baseline subsystem concept.
- 2) Perform system design analysis in conjunction with the component feasibility studies and tests.
- 3) Conduct component feasibility analysis and tests on the four major areas of concern: the catalytic gas generator, combustion chamber, the injection valves, and the ignition system.
- 4) Perform system integration and operation studies to define feed system dynamics and pneumatics; define effects of variable gas feed temperatures, establish fabrication, assembly and servicing techniques and procedures.

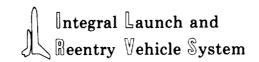
Alternate - Use earth storable bi-propellant system or a monopropellant hydrazine system. Use of either of these systems is not expected to have a significant effect on system weight. However, it is estimated that reusability



REPORT NO. MDC E0049 NOVEMBER 1969

will be lower and maintenance cost will be greater than for the clean burning $\rm 0_2/H_2$ system.

Estimated Cost - \$3,500,000 - \$4,500,000



ENTRY ENERGY MANAGEMENT

| 1970 | 1971 | 1972 |
|---------|----------|-------------------|
| PHASE B | PHASE CI | PHASE D { |
| | L | |
| | PHASE B | PHASE B PHASE C |

Figure 4-16

Problem - Reference trajectory techniques such as path controllers or final value controllers are not compatible with the requirements for a pilot in the loop, alternate landing site capability, or safety of the required trajectory. These techniques are tailored to low L/D spacecraft rather than lifting entry vehicles. An energy management system is required that is compatible with large lateral maneuvering requirements, using the adaptive capabilities of the pilot to provide effective flight path control with capability to reach an alternate landing site, and flexibility in the manner required to reach a landing site.

<u>Proposed Approach</u> - The proposed approach is to utilize a fixed base simulator program now being developed to include such inputs as a pilot, minimum heating reentry trajectories, lateral range maneuvering, optimum bank profiles, etc., to determine the control actions required to fly the vehicle from orbit to the intended destination so that it arrives at a predetermined point with the energy level and flight conditions for cruise and go-around, and then accomplish a powered approach and horizontal landing.

Alternatives - There is no existing simulator program to study entry energy management for vehicles of this type. Alternate approaches would be to develop pilot techniques and handling qualities requirements during the flight test and early operational program. Pilot-in-the-loop evaluation of the flying characteristics of these high L/D vehicles is also required to obtain data for use in establishing design requirements such as the amount of heat protection material on the sides of the vehicle vs the sideslip angle control that can be achieved.

Estimated Cost - \$400,000 - \$600,000

AUTOMATIC LANDING

| KEY MILESTONES | 1970 | 1971 | 1972 | 1973 |
|--------------------------------|------|-----------|---------|--------------|
| PROGRAM PHASES | | IPHASE CI | PHASE C | $\dot{\Box}$ |
| PREDICT FEASIBILITY | | | | T |
| SYSTEM REQUIREMENTS DEFINITION | | | | |
| COMPUTER STUDIES | | | | |
| SIMULATION EVALUATION | | | | |

Figure 4-17

<u>Problem</u> - A requirement exists for all-weather automatic approach and horizontal landing capability for both the Carrier and Orbiter vehicles in the powered and emergency unpowered mode. The first stage may be unmanned. Requirements for hardware definition, the capabilities for power-out back-up, and establishing touchdown dispersions must be defined.

<u>Proposed Approach</u> - Conduct studies utilizing a 6-degree-of-freedom digital computer program and a flight simulator program to evaluate various automatic control and landing schemes, and define the necessary additions and modifications to the promising systems to meet shuttle requirements. Those studies should be conducted for flight phases beginning prior to engine deployment and continue through touchdown.

Alternative - Presently there is no one automatic control and landing system that meets all the shuttle requirements for fail operational mechanization with sufficient redundancy to achieve necessary reliability, terminal phase energy management capability, and roll out guidance.

Estimated Cost - \$300,000 - \$500,000

CRUISE ENGINE VACUUM STORAGE

| KEY MILESTONES | 1970 | 1971 | 1972 |
|-------------------------|---------|------------|---------|
| PROGRAM FEASIBILITY | PHASE 8 | I PHASE CI | PHASE D |
| DEMONSTRATE FEASIBILITY | | A | |
| CONDUCT ANALYSES | | | |
| CONDUCT TESTS | | | |

Figure 4-18

<u>Problem</u> - Conventional turbojet or turbofan engines have not been used operationally with a requirement to remain in vacuum storage over a large temperature range. Vacuum effects on conventional engine subsystems should be investigated and evaluated. Engine operation after exposure to this environment must be demonstrated.

Proposed Approach - Conduct analyses on components and subsystems.

Run tests to evaluate the effect on lubrication and fuel systems under vacuum storage conditions.

Demonstrate lubrication system effectiveness after vacuum exposure.

Alternative - Use pressurized engine compartments for orbital missions.

Estimated Cost - \$1,500,000 - \$2,500,000

INTEGRAL TANK DESIGN

| KEY MILESTONES | 1970 | 1971 | 197 2 |
|--------------------------|------|--------------|---------|
| PROGRAM PHASES | | - | 3 |
| PREDICTED FEASIBILITY | | PHASE C | PHASE D |
| DEMONSTRATED FEASIBILITY | | | |
| ANALYSIS | | | |
| ENGINEERING STUDIES | | | |
| DESIGN LAYOUT | | <u> </u> | |
| COMPUTER STUDIES | | | |
| DEMONSTRATION | | | |
| ENGINEERING | | | |
| DESIGN LAYOUT | | | |
| COMPUTER STUDIES | 1 | | |
| TEST & EVALUATION | | | |

Figure 4-19

<u>Problem</u> - A requirement exists to develop and verify a structural analysis methodology for use in designing optimized structural units which integrate the vehicle airframe loads and the tank pressures and loads, and to determine the best approach to insulation, i.e., inside, outside with minimum structural attachments, and outside with maximum structural attachments to tank, but tolerating boil-off loss of fuel.

Proposed Approach - In addition to the normal design efforts of the definition and design phases, it is recommended that the following effort be accomplished:

- 1) Perform engineering trade studies to select candidate design approaches.
- 2) Prepare detail layouts of the candidate approaches.
- 3) Conduct computer program analysis of selected approaches.
- 4) Design and fabricate structural test samples of typical structural elements and joints.
- 5) Verify analytical predictions by testing the above structural specimens at design limit load and design ultimate load condition.

Alternative - Use conventional design approach of separate tank and airframe structural design and analysis. The effect of using conventional design will be that the system will be less efficient volumetrically and might be heavier.

Estimated Cost - \$800,000 - \$1,000,000

CRYOGENIC INSULATIONS

| KEY MILESTONES | 1970 | 1971 | 1972 |
|--|------------|------------|---------|
| PROGRAM PHASES | CPHASE B | I PHASE CI | PHASE D |
| PREDICT FEASIBILITY | <u> </u> | | • |
| REQUIREMENTS ANALYSIS & DEFINITION | | | |
| MATERIALS REVIEW & SELECTION FOR TEST. | | | |
| MATERIAL EVALUATION TESTS | ļ <u> </u> | | |

Figure 4-20

<u>Problem</u> - To attain an effective cryogenic tank insulation requires an investigation and selection of new materials and verification of reusability for reduced cost, low weight, improved reliability and maintenance, and long life.

Proposed Approach - Investigation of new materials and improved reinforcement techniques will require a three step program. First, systems requirements must be analyzed and desired insulation characteristics defined. Secondly, an industry search will be conducted to determine availability and applicability of materials. From these materials candidates would be selected for detailed material property and design information tests. The third step would be to conduct evaluation tests on these candidates. Testing would include:

- Reuse (reduced cost) Laboratory and large scale specimens will be subjected to chill down/fill simulation cycles and evaluated for structural integrity.
- 2) Material/Reinforcement (reduced weight) New foaming materials, better reinforcement techniques or processing techniques to obtain a lower density foam will be established in the laboratory and scaled-up in manufacturing areas.
- 3) Increased Temperature (performance payoff) Materials will be surveyed and evaluated in laboratory. PI resins will be foamed to obtain low density foam with increased temperature capability.
- 4) Gas Barriers (weight reduction) Materials (film and laminates) will be evaluated as to H₂ permeability in joint and non-joint configurations in the laboratory. Typical scaled-up specimens will also be subjected to permeability evaluation.

- 5) Non-Destructive Inspection (reliability, cost) Various methods will be evaluated on laboratory and sub-scale specimens as to efficiency, cost and reliability.
- 6) LOX Insulation (boil-off reduction) Various insulation systems/materials will be subjected to LOX impact testing to determine threshold energy for reaction.

Alternate - Use of current state-of-the-art insulations will degrade thermal performance resulting in increased weight, lower damage tolerance, and increased cost.

Estimated Cost - \$300,000 - \$500,000

COATED REFRACTORY METALS

| KEY MILESTONES | 1970 | 1971 | 1972 |
|---|---------|-----------|---------|
| PROGRAM PHASES | PHASE B | I PHASE C | PHASE D |
| PREDICT FEASIBILITY | | Δ | |
| SPECIMEN FABRICATION AND COATING | | | |
| REUSE AND DESIGN ALLOWABLE - Testing | | | |
| EMITTANCE MEASUREMENTS | | | |

Figure 4-21

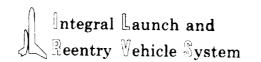
<u>Problem</u> - Need to establish the reusability and design allowables of coated refractory metals so that an efficient and reliable structure can be designed. Must establish the coating emittance characteristics under reuse conditions.

Proposed Approach

- 1. Reuse Capability Laboratory size (3 in. x 8 in.) specimens representative of typical heat shield constructions will be exposed to simulated flight profiles of temperature, pressure, and stress simultaneously and evaluated as to structural integrity.
- 2. <u>Design Allowables</u> Laboratory size (3 in. x 8 in.) specimens representative of typical heat shield constructions will be tested structurally after various amounts of simulated flight profiles of temperature, pressure, and stress are applied simultaneously.
- 3. <u>Emittance</u> Small coated samples with integral reference cavities will be exposed to simulated flight profiles of pressure and temperature with emittance being measured simultaneously.

Alternative - Use HCF which has limited information on material properties, joining techniques, and manufacturing techniques.

Estimated Cost - \$300,000 - \$400,000 Priority - Significant



REPORT NO. MDC E0049 NOVEMBER 1969

- 4.5.3 Additional development areas which do not qualify as technological breakthroughs or long lead-time supporting research, but which should be considered for definition phase effort are listed below:
 - o Fuel sloshing and baffling techniques requires testing to define slosh effects on launch configuration dynamics.
 - o Materials survivability testing to determine ability to withstand predicted environments.
 - o Implementation study, including preliminary ground and flight test planning, and program integration.
 - o Vehicle operations analysis including maintenance planning incorporating airline and military operational techniques.
 - o Vehicle maintenance facility requirements study.
 - o Payload size optimization.
- 4.6 Cost Summary A summary of estimated costs for the identified supporting research and technologies is shown in Figure 4-22. These research areas were not sufficiently defined during this phase of the study to be able to arrive to firm cost estimates. Configuration evaluation is probably the major technology and it would continue through all phases of definition, design and development. The funding shown for this area is for preliminary wind tunnel testing to perform configuration analysis and configuration optimization studies on the Carrier vehicle, some heat transfer and hypersonic testing of the Orbiter, and tests of the launch configuration including stability and control and interference heating for stage separation, both normal and abort.

The essential technologies should be solved prior to final design and acquisition and represent high risk areas. Failure to solve these problems could have serious impact on the program.

TECHNOLOGY COST SUMMARY

| ESTIMATED COST RANGE (THOUSANDS OF DOLLARS) | 8000 - 9000 3500 - 4000 2250 - 3000 4000 - 6000 (1) 3500 - 4000 | 4000 - 5000 1250 - 2000 2500 - 4500 500 - 750 3500 - 4500 400 - 600 300 - 500 1500 - 2500 800 - 1000 300 - 500 300 - 500 300 - 400 15,350 - 22,250 36,600 - 48,250 |
|---|---|--|
| TECHNOLOGY | ESSENTIAL – CONFIGURATION EVALUATION AERO HEATING TPS MATERIALS THERMOSTRUCTURES HIGH P _C ENGINE SELF TEST FOR ON-BOARD CHECKOUT | SIGNIFICANT — INTEGRATED AVIONICS DEMONSTRATION DATA BUS ELECTRONIC CONTROLS & DISPLAYS NON-COOPERATIVE REND EZVOUS GASEOUS O ₂ /H ₂ ACS ENTRY ENERGY MANAGEMENT AUTOMATIC LANDING JET ENGINE STORAGE INTEGRAL TANK DESIGN CROYOGENIC INSULATION COATED REFRACTORY METALS SUBTOTAL NOTE: (1) EXISTING FUNDED PROGRAM TOTAL |

7000

| 1 | | |
|---|--|--|